NUCLEAR ENGINEERING

VOL. 2 NO. 12 MARCH, 1957

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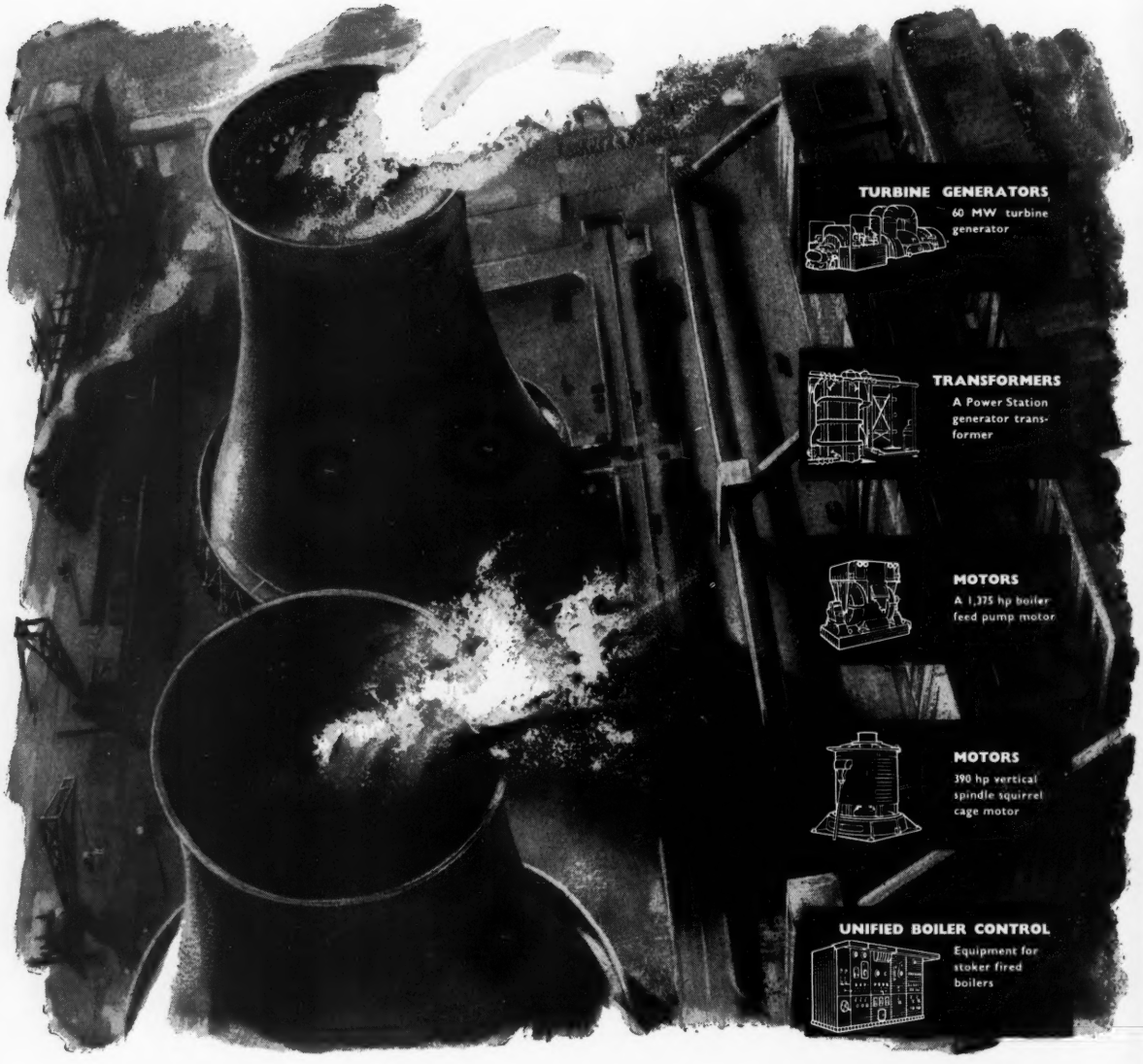

IN POWER STATIONS, as in every sphere of industry, the results of Metropolitan Vickers research, enterprise, and experience are clearly evident. Many advances in the design of equipment for power stations owe their origin to this great organisation.

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NUCLEAR ENGINEERING VOL. 2 NO. 12 MARCH, 1957

EDITORIALS

Optimization is Standard Engineering Practice

THE Thomas Hawksley lecture, sponsored by the Institution of Mechanical Engineers and held at Church House in collaboration with the B.N.E.C. on February 15, 1957, attracted a large gathering of engineers not only from the parent institution but also from the sister institutions. Sir Claude Gibb was able to speak to a capacity audience which was treated to a careful analysis of the problems besetting engineers in designing nuclear power stations. That these are numerous there can be little question, but what must have struck many hearers who have not been associated with such designs is the similarity of pattern between a nuclear power station design and the design of any large-scale plant.

Atomic energy still carries a certain glamour with which other fields of engineering find difficulty in competing, but atomic energy also unfortunately tends to carry with it an atmosphere of mystery which newcomers to the field penetrate only with reluctance. There seems to be an instinctive reaction to the mention of atomic energy characterized by such phrases as ". . . it must be wonderful to understand these things" and ". . . of course we never did that sort of thing in my day". This reaction is by no means confined to the non-technical grades and is a great hindrance to an appreciation of the significant features of nuclear power generation and the application of previous experience to new problems.

There is some excuse for the attitude perhaps with the more advanced types of reactor when the physicist and the chemist will be involved in designs to a very late stage; but with the gas-cooled, graphite-moderated type, and the pressurized-water also, once the physicist has produced the basic core information and the metallurgist has defined the compatibility problems, design is almost entirely a matter for the mechanical engineer who should already be familiar with the normal processes attendant upon "optimization". Admittedly, certain parameters such as shielding, which have previously been the prerogative of the physicist, must be included in the overall assessment, but now that the fundamental data are available the figures can be fed into the optimization equations in much the same way as pressure vessel thickness, blower power and so on.

Aspects of reliability and safety will figure predominantly in any design consideration, but this should not represent a very considerable departure from normal practice. Once an inherently safe type of reactor has been chosen and appropriate limits set on the invested reactivity and the maximum rate of increase of reactivity, the most important consideration is the familiar one of economics. Faults in design or construction necessitate excessive shut-down of the reactor, thereby decreasing the load factor and increasing the cost per kilowatt. This reasoning applies to the design of any plant, however, in the same way that the optimization of the main parameters is basically concerned with the final cost of the end product.

Sir Claude's exposition demonstrated this aspect with great clarity. Once the issues involved are understood—and these, if unfamiliar, are by no means excessively abstruse and are largely those found in any plant generating electricity from a furnace, whether fuelled by fissile or fossil fuel—the processes of optimization requires the application of standard engineering rules and practice.

Once detailed design is under consideration, then whether fissile or fossil fuels are involved is immaterial. Charge and discharge gear, for example, will require a design peculiar to the particular reactor under consideration, and the overall design must be integrated with that of the pressure vessel, but only straight mechanical engineering is required. The elegant solutions to such mechanical engineering design problems will determine the rate at which capital cost (and hence cost per kWh) will decrease and will be largely responsible for the establishing of fissile fuels as the main source of energy and for the selection of the most economic reactor types.

Declassification and Patents

OVER the past few months steps have been taken to cut down the hold-ups caused by the classification of information and the restrictions imposed by patents. In September of last year the governments of the United States, Canada and the United Kingdom entered into an agreement whereby patents owned by individual governments were made available to the other two governments on similar terms to those operating in the country of origin. The patents included in this category were those taken out or applied for prior to the arbitrary date, November 15, 1955. This particularly simplifies the position of patents which arose from Combined Policy Committee inventions, being derived from wartime collaboration between the three governments. The inventors in these cases had previously assigned their rights to the governments employing them at the time of the study, who were then responsible for upholding them until a more permanent settlement could be made.

In the field of atomic energy particularly, the patent situation is somewhat confused. Patent offices have been inundated with applications from both government-sponsored organizations and industrial concerns and, initially at least, no staff was available with the necessary experience to handle them. As a result, many patents have been issued which in other fields of engineering would have received much closer examination in the early stages. Some patents are also of an extremely broad and comprehensive nature, a notable example of this being the original application by a group under Fermi and including Pontecorvo for a patent on the moderation of fast neutrons. It is understood that the failure to complete a final settlement of this particular issue has been responsible for some of the delays in framing the tripartite agreement.

Tripartite Declassification Guide

To enable a common policy to be adopted on the release of information which might have a military significance, the Tripartite Declassification Guide is drawn up by the U.S., the U.K. and Canada. This has recently been revised to include a number of subjects previously not in the declassification category. The last important change in policy was, of course, prior to the Geneva Conference, when for the first time very large quantities of information were made available. It should be noted, however, that revision of the Declassification Guide does not automatically declassify documents; it merely determines what types of information should or can be released. The information then becomes publicly available when reports, drawings, photographs, etc., have been reviewed and certified to be declassified under the new guide. Since the last declassification a new aspect of security has become of importance, that is, the aspect of commercial security rather than military security.

Interpretation of what constitutes a commercial security risk is open probably to a wider interpretation (and to a narrower viewpoint) than is the security risk, and the new policy which has been adopted by the three countries does not necessarily mean that a large body of valuable detailed information is to be released. For example, fuel elements are included in the new Declassification Guide, but it is known that the manufacture of fuel elements is considered to be one of the most important commercial secrets. Also included in the Guide is the recovery of spent fuel, the design and operation of plants for chemical recycling and detailed production figures of uranium ores and concentrates. These last figures will be of value to those industrial concerns and financial corporations, etc., who have become concerned about the availability of fuels.

One cause of concern is the length of time required to go through the available reports and documents to determine their new classification. It is likely that reports issued in the next few months will be those that were originally issued some two years ago and may even be older than that. This implies that the work referred to may be as much as three or four years old, and on those subjects that have up to the present time been completely *sub rosa* much earlier background information also must be declassified. It is to be hoped, however, that at the same time as the revision of old papers is going on, new papers and reports as they are produced will be immediately considered under the new classification and their appropriate class be allocated so that if these are publishable no delay is involved in the material becoming available.

The Long-term View

Decisions concerning the commercial security of some of these documents will not be easy to make, and no doubt as the first industrial designs have only recently been completed there will be a tendency for much detailed information to be withheld on the grounds that it would be of considerable assistance to a country in which the gas-cooled, graphite-moderated reactor has not received much attention. Whilst this to a limited extent is true, it should also be remembered that failure to publish also encourages other people to withhold information: the dissemination of information is a give-and-take process. A not uncommon attitude is a willingness to read and accept all information that is proffered, but to offer none back in return. This can only operate gainfully for a limited period and it must be generally acknowledged that too coy an approach to this subject of general release imposes a continuously constricting action upon the industry and results in an overall slowing down of progress. In this context, it is interesting to note how often the opinions of the public relations organizations, who after all have been employed as experts in these matters, are over-ruled by those responsible for the designs and therefore less able to take a dispassionate and long-term view. One of the most important points to bear in mind is that although this is a commercial race in many aspects, there is no reason why everybody should not run together successfully; the opportunities are so considerable. Ultimately, the success of a particular company will depend upon the company's efficiency, and efficiency only, whereas security restrictions will only tend to create an overall drag on all those competing.

Comments on the News

EURATOM and O.E.E.C.

The most recent reports indicate that the treaty setting up an atomic energy pool would be signed shortly and ratified during the summer. The six member nations of EURATOM—France, Germany, Italy, Belgium, Holland and Luxembourg—appear to have reached a satisfactory compromise on their various disagreements and a team of three has recently made a visit to the U.S.A. to discuss American co-operation, particularly with respect to fuel supplies. Some complexity enters into the whole question of fuel, as Belgium is already committed to contracts with the U.S.A. and the U.K. for supplying uranium from the Belgian Congo, whilst the United States has responsibilities towards the international agency, apart from bilateral agreements with individual countries.

During this last visit a target of 15,000-MW generating capacity within the next ten years was discussed, followed by a visit to the Shippingport station now nearing completion. In a joint communique issued by the U.S.A.E.C. and the State Department following the meetings, the U.S. Government welcomed the initiative taken, anticipated association and foresaw a fruitful two-way exchange of experience and technical development. The generating target was considered feasible and would not be limited by fuel availability. General opinion appears to assume that EURATOM would begin the programme with a pressurized-water reactor, but equal consideration must be given to the Calder Hall type, although this will no doubt be dependent upon the experience gained with G_1 and G_2.

Partial participation by Britain in the EURATOM pool now seems unlikely, although the increasing interest being shown in the common market proposals may lead to a reassessment. Present commitments and responsibilities would make full entry impossible, but if the common market is established, with Britain a full member in the heavy engineering field, some association would seem inevitable. On the other hand, if EURATOM confines its efforts to the pooling of electricity resources only, British participation would seem to be unnecessary, the more complex aspects of international collaboration being handled by O.E.E.C., to which Britain is a major contributor.

At the end of last month the Nuclear Energy Steering Committee of O.E.E.C. announced its first firm proposals. The committee was set up in July last year to examine a number of co-operative ventures. The two main projects submitted are, first, a £5¼ million chemical processing plant to go into pilot operation in 1960 and, second, a programme of building five research reactors at a cost of £10½ million. These would comprise a fast breeder reactor, a liquid-metal-fuelled reactor, a materials-testing reactor, a homogeneous aqueous reactor and a pressurized-water reactor. Sites for the chemical plant and the reactors have not been chosen, but the major member nations would all be pleased to act as host. O.E.E.C. has a power project under consideration, but it would appear reasonable for its attentions to be concentrated on research and development and the provision of some services, leaving EURATOM to handle the "commercial" side. In any event, the terms of reference of these two organizations should be more clearly presented and if these have not yet been defined, then before EURATOM is ratified the position should be clarified.

NUCLEAR SHIP PROPULSION

In this issue of *Nuclear Engineering* (page 93) we present some of the problems that face the shipbuilder who is thinking in terms of nuclear propulsion. Mention, however, is only made of the basic design problems and those of international collaboration and the assumption has been made that the financial aspects of nuclear propulsion have already been settled. For a naval programme this may be of a second-order consideration, but for a merchant fleet economy is a prime essential. At this juncture there can be no question of the United Kingdom going ahead with the construction of a nuclear-powered vessel. The types of reactor system at present appearing to offer the greatest promise are the pressurized-water reactor with possibly organic moderation and the high-temperature gas-cooled reactor, but these types have yet to pass out of the feasibility study stage and many months must pass before any conclusions can be drawn either on their operational value or on their economic value. The question, however, that must shortly be answered is whether one should wait for an economic system to be developed before entering into a merchant ship programme, whether the experience that would be gained on the construction of an uneconomic nuclear-powered vessel would be well worth while, regardless of the expense. There are clearly dangers in leaving the initial studies to the navy on the grounds that they can afford it, as ultimate operational requirements may demand a different final approach to the problem of nuclear propulsion.

In the meantime, the U.S.A.E.C. and the Maritime Administration have jointly announced a long-range programme aimed at developing reactor systems for commercially competitive propulsive power for merchant ships. This is in addition to the work now progressing on the development and construction of the first nuclear-powered merchant ship announced by President Eisenhower on October 15, 1956. Under the joint programme, the U.S.A.E.C. is responsible for financing and directing the development of merchant ship reactors, whilst the Maritime Administration is responsible for financing and constructing ships, for propulsion plant and nuclear reactors which have passed beyond the development phase. Under this long-term programme the two agencies have contracts with private companies for six design feasibility

studies. Of these, three envisage the use of a closed-cycle gas turbine as the prime mover. It is important to note that, although the development programme has been formalized, the feasibility studies have yet to be made.

We in the United Kingdom must await the results of the generalized feasibility studies now in progress before any detailed programme can be set out, but it is to be hoped that when the time comes that firm decisions can be taken, full co-operation can be organized between the ship builders and ship owners and the reactor design teams so that an integrated study can be made with the desirable characteristics of both reactor and ship operation built in at one and the same time.

FUSION CALCULATIONS

In last month's issue, *Nuclear Engineering* delved into some of the fundamental aspects of generating power from the thermonuclear reaction. In his article (page 60) Dr. Linhart draws an analogy between the familiar chemical flame and the thermonuclear flame and calculates some of the major parameters which must be satisfied in the design of any reacting plant. From these calculations, it is clear that there is no fundamental reason why a nuclear flame cannot be generated and maintained and it is probable that in the very near future the design of a thermonuclear reactor will be almost entirely in the province of the engineer. That is not to say that there are not many system and material problems to be answered, but with the continued lack of detailed information obtainable on experiments conducted in this country and in the U.S.A. no real indication can be given of the state of advancement (or otherwise) of this particular technology. Certain clues have been dropped which have shown that an intense programme has been under way in the U.S.A. for some time and that work on a similar project in this country has not been neglected. It is known, for example, that A.E.I., through their Aldermaston laboratories, are engaged on contract work for the A.E.A. and that a number of other companies are developing equipment whose ultimate significance is connected with the fusion programme. It would appear, also, that even those who have been intimately concerned with developments, differ widely in their views on the time required to produce an operational zero energy system; opinions range from five to twenty years. What is perhaps significant is that five years is being quoted at all.

U.S.A.E.C. RADIATION REGULATIONS

The U.S.A.E.C. has issued a regulation effective from February 28, establishing standards for the protection of atomic energy workers and the public against radiation hazards arising from activities licensed by the Commission. The regulation is, in effect, the same as that first published in July, 1955, as a proposed rule, but it has been modified in small details as a result of consultations with a number of interested persons and organizations. Standards are set up in the regulation for the handling of all radioactive materials subject to Commission licensing, and limits are prescribed governing the exposure of workers to external radiation, concentration of radioactive material which may be discharged into air or water and the disposal of radioactive waste.

The permissible limits of exposure agree substantially with the current recommendations of the National Committee for Radiation Protection in the *N.B.S. Handbook*, 1952. The weekly permissible dose, for example, is specified as 600 m rem for whole-body radiation with a half-layer thickness greater than 1 mm soft tissue, a further factor of 2 in safety being required for the blood-forming organs, gonads and lens of the eye. For radiation with a half value of less than 1 mm soft tissue, the skin dosage is increased to 1,500, the other three categories remaining the same; similarly, the hands and forearms, or feet and ankles, head and neck, of any radiation have a prescribed maximum permissible level of 1,500 m rem/week. One rem is taken to be equal to one rad of X or gamma radiation, one rad of X or beta radiation, 0.1 rad neutrons or high-energy protrons and 0.05 rad particles heavier than protrons with sufficient energy to reach the lens of the eye. The rem is further defined as being equivalent to $996 \times 10^6 n/cm^2$ thermal or $14 \times 10^6 n/cm^2$ of 3 MeV and higher.

The principal changes in regulations since the first proposals concern the rules to be applied following an excessive dose. The additional exposure must be compensated by ensuring that the quarterly (13 week) total dose be held to a maximum of ten times the permissible weekly dose. Following an overdose also, the exposure of a worker must be limited to 10% of the permissible limit until this average dose has been achieved.

INDUSTRY v. U.S.A.E.C.

Whilst the Gore Bill, which was not accepted by Congress prior to the last recession, at the time created some bitterness between the advocates of a Federal-inspired power programme and those of a purely industrial programme, it seems probable now that a compromise will be found and that the A.E.C. will build power reactors of those types which industry would regard as being somewhat questionable from an ultimate economic point of view, leaving industry to exploit those types that have shown early promise. At the same time, industry will be encouraged to invest more capital by the Federal Government accepting insurance liability over and above that available from the insurance companies ($65 million) to the extent of $500 million minimum. As previously pointed out (*Nuclear Engineering*, 1, 138), the limitations imposed by the insurance companies on single indemnities was not inspired by lack of confidence so much as lack of flexibility in the system. The small coverage offered, however, was inclined to discourage investors and utility companies alike, but with the additional security a considerable expansion in investment can be expected.

WELSH POWER STATION PROPOSAL

An unusual approach to the erection of nuclear power stations has been taken by a number of M.P.s from Wales. A deputation representing the Welsh Labour group of members of Parliament met the deputy chairman and other officials of the C.E.A. to urge the Authority to consider the claims of Wales in planning the further execution of a nuclear power station programme. Later the C.E.A. representatives met senior officials of the Cardigan County Council, who made strong representations concerning the particular suitability of the Cardiganshire coast for nuclear power stations. Compared with the more familiar attitude that nuclear power stations are desirable provided they are built elsewhere, this attitude comes as a refreshing surprise. Although no doubt its turn will come, Cardiganshire would appear to be an unnecessarily long way from the heavy load centres existent in South Wales. Furthermore, with the ever-increasing need for steel, the load demands in these areas are liable to increase sharply in the course of the next few years.

Problems of Nuclear Ship Propulsion

Nuclear propulsion of ships cannot come about simply by the installation of a land-based design in a sea-going craft. Ship propulsion raises many issues which are not encountered in stationary power units; these concern basic design, detailed engineering and international collaboration.

The S.T. Spyros Niarchos, 47,750 tons, built by Vickers-Armstrongs (Shipbuilders) Ltd. Still larger tankers offer the greatest scope for the economic use of nuclear propulsion.

THE major differences between designing a nuclear power unit for base-load electricity production and for ship propulsion concern both the operational characteristics of the reactor system which can, in turn, materially affect the nuclear physics of the design and the detailed engineering of the unit. The propulsion unit must have a maximum reliability built in, but at the same time must be designed to operate under bad-weather conditions when the base of the reactor and its associated installation is not a fixed platform but one subject to violent movements. Furthermore, built into both nuclear physics and engineering design must be additional safeguards to provide against radiation hazards following a collision, which may cause a major disruption of the ancillary gear, possible fracture of the shielding and, in the most serious instances, foundering. An immediate pollution hazard would arise from sinking in territorial waters or in currents flowing towards the land, but fish contamination is of importance anywhere in the ocean.

Invested Reactivity

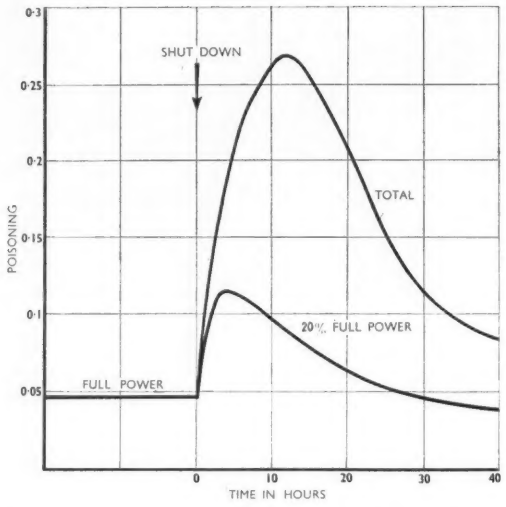
It is desirable that the power unit should always be in a condition where start-up can be virtually immediate, but safety considerations impose limitations on invested reactivity. As a result of xenon poisoning following shut-down, these two conditions are opposing; to overcome the decrease in reactivity brought about by the build-up of xenon, a greater reactivity must be built in than is otherwise necessary. The xenon concentration in a reactor is maintained at a low equilibrium level during constant running largely by neutron absorption. Being a daughter product, however, rather than a direct fission product, when power is reduced—power is proportional to neutron flux—the concentration rises and the less the reduction in power the less is the poisoning effect. The advantage to be gained by complete stop-start versatility may be more than counterbalanced by the disadvantages involved in providing excessive reactivity in the clean cold and equilibrium running states. It should also be borne in mind that, although motor ships can be run up to full power only a short time after switching on, conventional steam systems require a considerable start-up period from complete shut-down conditions where boiler fires are out and boilers are cold. It may be possible to organize the operation of the ship so that start-up during peak poisoning conditions is never necessary, short-term manœuvring being undertaken on auxiliary propulsion units. A fresh approach towards estuary and harbour running could allow for this, although break-down at sea would present greater difficulties.

At the same time, a material fraction of the total power necessary to propel a ship is required for heating and lighting and other auxiliary functions even in port. A large liner, with its very considerable "hotel" demands, may consume in port as much as 10% of the total power required at sea. This will admittedly peak during the day and drop off at night, but even a purely cargo boat requires some 5% of at-sea demands for the operation of winches and domestic equipment. The turn-round time of these two types of ship is relatively long, and in the past, for economy reasons, it has been necessary to install auxiliary units to supply this stationary power. Tankers with their short turn-round time may use one of the main boilers to provide the considerable steam requirements of the pumps, but motor tankers have auxiliary boilers installed for this purpose.

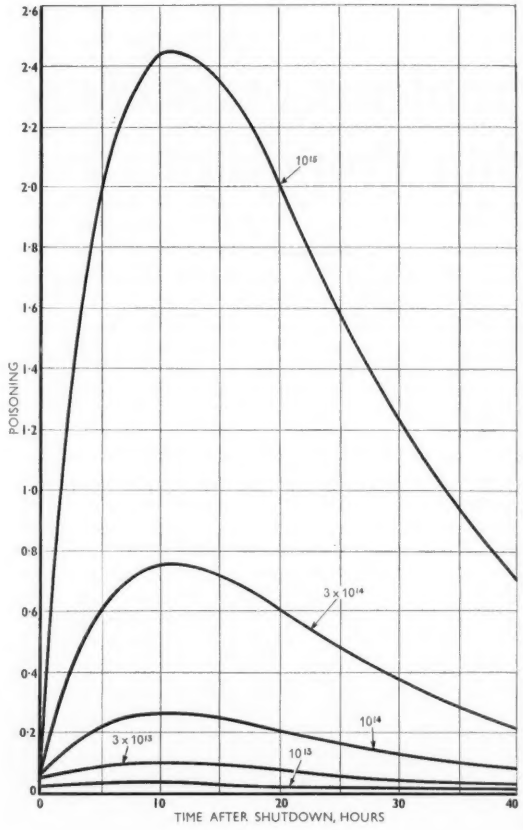
A change in approach towards the provision of these auxiliary supplies in a nuclear-propelled ship could permit the economic utilization of the main reactor system. This would mean that, apart from major overhauls, the reactor would run continuously (i.e., at a reduced power only in port) and the xenon poisoning effect would thereby be decreased. This is desirable even if in addition to running the auxiliaries it is necessary to install dumping facilities. In any event, at least initially, some dumping of power may be necessary as giving additional flexibility to the heat-transfer system, the capacity of which may be strained if the ship were required to operate for a protracted period of time with rapid changes in power demands such as might be encountered when entering difficult tidal estuaries.

Dumping steam from a ship at sea or in an estuary would present no problems, but in confined spaces it is possible that some embarrassment would be caused, particularly in closed basins. This cannot be acute, however, until a large number of nuclear-powered ships can be expected to forgather in a closed area, and no doubt when this state of development has been reached some excess power could be usefully "exported" to the dock. The capital cost of installing adequate dump facilities for, say, 10% of the total power should not be excessive.

At first vessels will require auxiliary power units capable of at least maintaining leeway in the event of a major break-down. Whether this will always be deemed necessary will depend upon the proven reliability of installations and whether it ever becomes economical to install two distinct reactor units rather than one large unit. Certainly to begin with the single large unit will be considerably more economic and probably easier to design to fit into the ship's architecture. At present, nuclear propulsion units are only envisaged as being applicable to large installations with shaft horse-powers exceeding 20,000, but as



Comparison of the xenon poisoning effects when a reactor is shut-down from full power (corresponding to a flux of 10^{13} n/cm^2-sec.) to 20% full power and to zero power.



(Right) Xenon build-up following complete shut-down of a reactor operating under equilibrium conditions at various flux densities. Maximum fluxes are likely to be limited to about 10^{14} n/cm^2-sec. in propulsion units.

time goes on the cost of smaller units will decrease. Nevertheless, it is likely that the cost of one large unit will always be significantly lower than the cost of two units of half the size, but in this context it should be noted that the U.S.S.R. ice-breaker is reported to have two reactor systems installed.

Engineering Design

Many of the engineering problems introduced by the installation of a reactor system into a ship are not peculiar to nuclear work. The consequences of failure may, however, be more serious. As a result, considerable development will be required to produce sound mechanical designs which will infallibly withstand the arduous conditions encountered in a vessel. In the main, the extension of established principles will be sufficient and designs can be based on experience already obtained in the operation of sea-going plant. The design of a system always to fail safe is not an entirely new philosophy in marine engineering, but again the consequences of this not being followed could be very much more serious.

As distinct from a land-based installation where the fail-safe condition must also be rigorously applied, the control system on a ship cannot rely on gravity. Furthermore, not only can it not rely on a constant acceleration in a given direction, but it must be designed to accommodate a changing acceleration in directions which may be as much as 50° away from the normal. This applies, of course, also not only to the control gear but to other sections of the plant: but it is with the control-rod and safety-rod systems that this problem is likely to be most acute and the safety rods must operate even if the ship turns turtle. Similarly, a land-based installation will never have to withstand violent shocks caused by collisions. There are approximately 50 serious accidents per year in which ships falling into the range where nuclear propulsion is a practical proposition are involved. Shocks from other causes such as mines must also be guarded against. The land-based plant will not have to contend with vibration, at least in large installations (apart from failing safe in earthquakes), whereas in a ship a certain amount is always present and the frequency and amplitude can vary considerably. The salt-laden atmosphere that all gear must work in is a problem only too familiar to marine engineers. The failure of supplies is also likely to be more acute in marine installations than in land-based plant. There is no grid system that auxiliaries can be tied to and provision must be made for the total failure of all supplies. The failure of coolant water is a familiar consideration to the nuclear engineer and whereas at sea, and even in port, water will always be immediately available, provision must be made for the possibility of stranding. Although the complete stranding of a vessel may be considered highly unlikely, inlet ports could rise above water level or be buried in mud.

Following a collision and sinking, the conventionally powered vessel is only a danger to other shipping from the point of view of obstruction, but for a reactor-powered vessel long-term corrosion, with the possible disintegration of fuel elements and the release of entrapped fission products into confined waters, cannot be ignored. There is every reason to believe that a reactor pressure vessel would in any case have to be built so strongly that mechanical shocks and even major collisions would not rupture it, but subsequent corrosion can alter the picture completely and an inherently stable fuel element in the presence of sea water is therefore necessary. The consequences of a fire could also be more acute in a ship and lead to the failure of improperly designed control systems and the destruction of vital parts of the containment.

With land-based plant no limitations are imposed upon space and the design of fuel changing equipment can be based solely on the operational design requirements of the reactor. This cannot be the case in a ship and, at best, only limited fuel changing can be contemplated at sea. More fundamental operations can be accommodated in dock, but a faulty element cannot be allowed to shut-down the reactor for more than a minimal period when the ship is at sea and provision must therefore be made for emergency changing or temporary disposal when out of reach of land-based apparatus and also in unpleasant weather conditions. This aspect will require some of the most careful engineering design of all and, initially, it may be concluded that such a facility cannot be installed and a fault in a fuel element would require propulsion by the emergency units only, and even towing into port. This would be a highly costly enterprise for a large merchant ship, and if fuel-changing provision is not made the reliability of the fuel elements must be unquestionable. It is interesting to note that in the eight months' operation of the first Calder Hall reactor two faulty fuel elements have been found. This is considered to be a low figure, but would represent serious hold-ups in a marine propulsion unit if no provision for faulty element disposal had been made.

Operational Control

The propulsion unit differs from the land-based power station also in operation, as short-term power demands can vary considerably. Some mention has been made of the capacity of the heat-transfer system and the advisability of providing dumping equipment, but the economic and safe operation of the various load-adjustment facilities calls for a new approach in control engineering. With Calder Hall, and probably with the first base-load nuclear power stations, the grid system will absorb detailed changes in output and long-term changes can be based on the desirable reactor outputs rather than on load demands—conventional-type stations taking up the necessary variations. A ship, however, is an isolated unit which cannot be tied into any large capacity system and the power unit must be able to follow the detailed changes in demand imposed upon it. This does not mean that the reactor must be able to follow in detail the changes in power, but the various parameters such as control-rod position, primary coolant flow, temperature and pressure, secondary coolant flow, temperature and pressure, turbine throttles, dump valves, etc., must be so organized as to always provide the requisite heat balance and maximum reserve power concomitant with safe operation in the most economic manner.

This almost certainly calls for computer control rather than manual control and much development will be required to enable simple, easily serviceable designs to be evolved, which have the necessary flexibility and reliability built in.

International Agreements

It is likely, however, that the greatest problem to be solved in applying atomic energy to ship propulsion lies outside the scope of the engineer. This concerns the establishment of international agreements covering the operation of reactor-powered ships. It is not envisaged that any unit should be designed which would allow, conceivably, the discharge of active effluent into the sea, and this has been regarded by all engineers as an *a priori* consideration. But the establishment of international standards of containment, safety factors and the like must be concluded before a merchant vessel can be operationally successful. Similarly, insurance coverage must be decided before any ship can put to sea. Sufficient complexity is already found in the shipping arrangements that have been made for the transport of fuel elements from the heavy-water reactor under construction in Australia back to this country, to indicate the very much greater issues that are involved in the operation of a nuclear-propelled merchant fleet. Fortunately, through the international shipping bodies, established machinery is in existence which could be adapted to consider such rules and regulations as are deemed necessary. Inevitably, however, discussions over details will be lengthy and the limited knowledge of reactor engineering that is available outside the few major powers will exacerbate the frustrations that are only too familiar when formulating international agreements.

Problèmes de la Propulsion Nucléaire des Bateaux

La conception d'un système de réacteur pour l'installation dans un bateau diffère de sa contrepartie terrienne tant en ce qui a trait aux détails mécaniques qu'en ce qui concerne la physique nucléaire. Le groupe d'énergie d'un navire devrait pouvoir fonctionner à une puissance soutenue pendant de longues périodes suivies de demandes irrégulières sur le rendement, mais tout en permettant toujours à la puissance entière d'être disponible à tout moment requis. Par suite de l'accumulation de xénon dans le réacteur à la suite d'un arrêt, cette flexibilité de démarrage implique de gros emmagasinements de réactivité, ce qui est à l'encontre des conditions de sécurité idéales. Une modification de vues tendant vers la prévision de fournitures auxiliaires dans les ports peut permettre l'utilisation économique du groupe d'énergie principal et la réduction de l'intoxication par le xénon.

Problem des Schiffantriebs mittels Atomkraft

Der Entwurf eines Reaktoren-Systems für den Einbau in einem Schiff ist von seinem Gegenstück auf dem Lande sowohl in mechanischen Einzelheiten als auch in der Atom-Physik verschieden. Die Kraftanlage auf einem Schiff muss in der Lage sein mit gleicher Leistung während langer Zeitspannen zu laufen, denen Zeiten folgen, wo die Anforderungen an die Leistung unregelmässig sind, wobei jedoch die volle Leistung in jedem Moment zur Verfügung stehen muss. Infolge der Entwicklung von Xenon in dem Reaktor, die auf das Abschalten folgt, verlangt Geschmeidigkeit beim Wiederanfahren eine zugehörige grosse Reaktivität, und dies Steht im Gegensatz zu den Bedingungen für die Sicherheit der Anlage. Ein Wechsel in den Ansichten über die Beschaffung von Hilfsanlagen im Hafen könnte es gestatten, dass die Hauptanlage wirtschaftlich ausgenutzt und die Vergiftung durch Xenon reduziert wird.

Los Problemas de Propulsion Nuclear de Buques

El diseño de un sistema de reactor para ser instalado en un buque difiere de su contraparte terrestre, tanto en detalle mecánico como en la física nuclear. La unidad de fuerza en un buque debe ser capaz de funcionar a fuerza sostenida durante largos periodos, seguidos por demandas irregulares en cuanto al rendimiento, pero con todo permitiendo que haya plena fuerza disponible en cualquier momento dado. Debido a la generación de xenon en el reactor después de ser parado, esta flexibilidad de arranque implica gran actividad invertida, lo que es contrario a las condiciones ideales de seguridad. Un cambio en las ideas con respecto a la provisión de abastecimientos auxiliares en los puertos puede permitir que la unidad principal de fuerza sea empleada económicamente y que se consiga la reducción de envenenamiento por xenon.

Berkeley Nuclear Power Station

Further Details of A.E.I.-John Thompson Design

IN *Nuclear Engineering* for January, reference was made to the C.E.A. station at Berkeley, Gloucestershire, for which a contract had been placed with A.E.I.-John Thompson Nuclear Energy Co. Ltd.—the consortium composed of Associated Electrical Industries Ltd., the John Thompson group, Balfour, Beatty and Co. Ltd. and John Laing and Son Ltd.—and brief particulars were given of the station. Whilst much of the detail design cannot yet be released, it is now possible to say a little more about this station.

Berkeley follows the broad principles of Calder Hall more closely than do either of the other two stations for which contracts have been placed. It is also the most conservatively rated. The main departures from Calder Hall are as follows:

1. Increased capacity.
2. General site plan and layout.
3. Use of eight heat exchangers per reactor instead of four.
4. Provision of on-load fuel changing.
5. Axial blowers in place of radial.
6. Method of control.
7. Application of computer techniques for gas monitoring.
8. Method of erection.

Capacity

The total installed capacity planned for Berkeley is 320 MW (four 80-MW turbines) with a net output of 275 MW compared with the approximate 75 MW of Calder.

General Layout

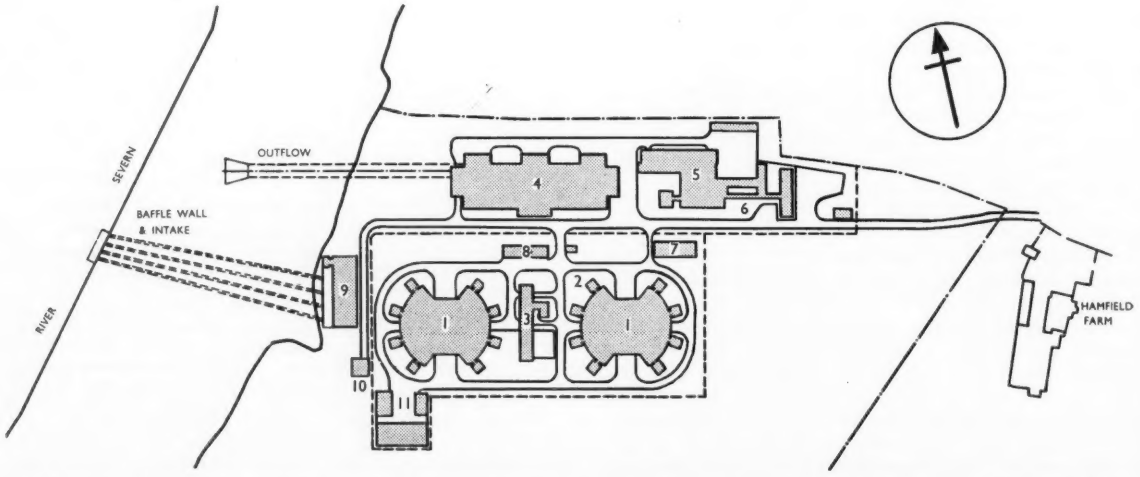
The general layout of the station can be seen from the accompanying site plan. The two reactors, instead of being disposed at either end of the turbine house, are placed fairly close together with a common cooling pond for irradiated fuel disposal and have grouped around them the ancillary buildings, such as fuel-element storage and the like, the whole being located within an enclosed area. The turbine house is outside this area.

The eight heat exchangers associated with each reactor are not arranged evenly around the circumference, but are symmetrically disposed in groups of four on each side of their reactor house, each group covering an arc of some 100° (the angle between adjacent units is actually $33\frac{1}{4}$°). There are two blower houses for each reactor, each being associated with four heat exchangers.

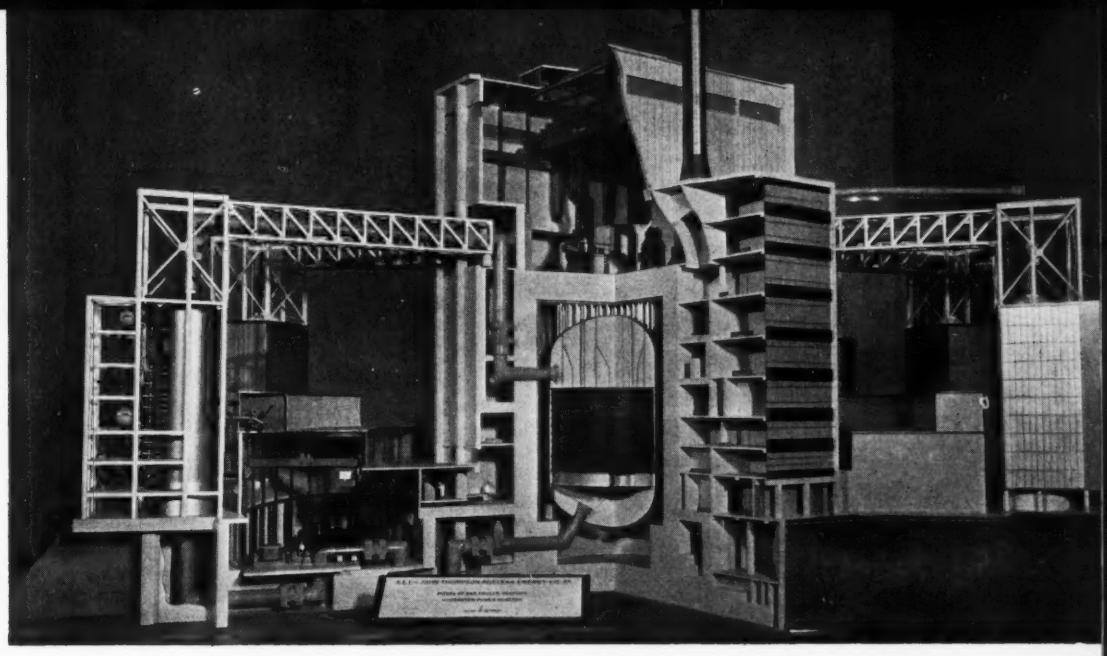
The general disposal of apparatus in the reactor house is shown in the illustrations on the pull-out opposite page 102.

Pressure Vessel

The pressure vessel is a dome-ended cylinder with overall dimensions of some 80 ft. overall by 50 ft. in diameter and is built of 3-in. plate. Unlike Calder, where the pressure vessel was built in sections externally to the reactor house, each section being lowered into place inside the completed shielding, the present vessels are scheduled for construction in their final position, the building being raised around the vessel as the construction proceeds. This will save the extremely heavy lifting that would otherwise be required.



Site plan of the Berkeley station: 1 reactor; 2 heat exchangers; 3 cooling pond; 4 turbine hall; 5 workshop; 6 canteen; 7 fuel-element storage; 8 carbon dioxide store; 9 cooling water pump-house; 10 sewage works; 11 active waste treatment.

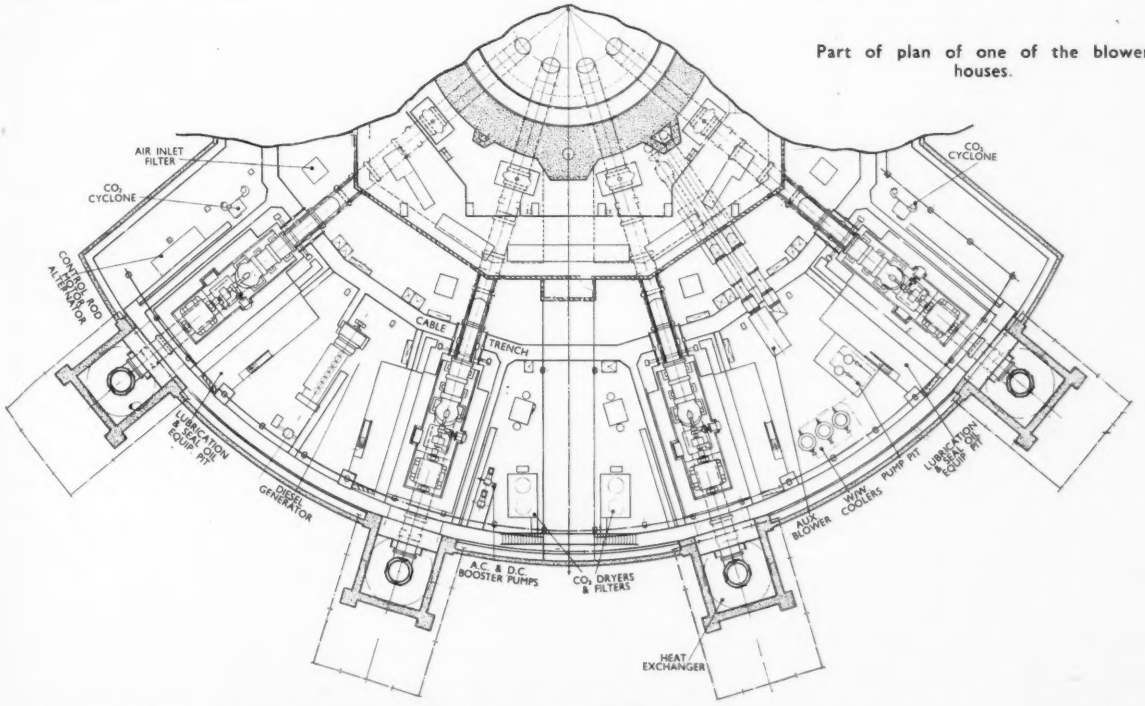


Sectioned model of the station.

As is mentioned on a later page describing the civil engineering works, the bottom dome is to be fabricated alongside the final position, to allow construction work to proceed independently and then moved into position by means of a heavy bogie system running on rail tracks. One of the interesting features of the pressure vessel is the edge preparation of the plates. A very considerable amount of experimental work has already been carried out on the design of the joints which are all arranged so that, as far as the vessel itself is concerned, overhead welding is completely eliminated, even in the construction of the bottom dome. This, incidentally, consists of 63 plates, with a total weight of some 200 tons.

The method of support differs from Calder in that the legs are shorter and the "A" frames are not inverted. There are 18 legs, each with two supporting feet, so that the vessel is supported on 36 spherical bearings.

There is no gas inlet manifold, the mouths of the ducts entering the domed end normal to the surface. The outlet ducts are arranged radially in the cylindrical portion as before. The vessel is lined with a $\frac{1}{4}$-in. plate lining, from a point near the bottom of the graphite upwards to reduce temperature gradients, the annular space between lining and vessel being separately cooled.



Part of plan of one of the blower houses.

Shielding

Thermal shielding above the pressure vessel is by means of $5\frac{1}{16}$-in. steel plate with a 2-in. air gap between it and the concrete biological shield. Below the vessel, 4-in. plate is used. Thermal shielding at the side of the pressure vessel consists of two $\frac{1}{2}$-in. plates with a $1\frac{1}{2}$-in. air gap.

Biological shielding is provided by concrete 8 ft. 6 in. thick at the sides, the top being 10 ft. 6 in. thick in actual

fact, but having an equivalent thickness of 8 ft. when allowance is made for the voids for the control gear. For cooling the shields, induced-draught fans are used, exhausting through filters to the atmosphere via two steel chimneys at about 240 ft. above ground level.

Graphite

The graphite core consists of a large number of independent vertical columns of bricks and tiles, each being individually supported through ball bearings by a diagrid structure approximately 4 ft. 7 in. deep. The graphite assembly forms a 32-sided prism some 48 ft. across the corners and 30 ft. high. The stability of the structure is preserved throughout by flexible bracelets. A number of cast-iron cap plates are provided that serve to locate the fuel channels and the burst-slug detection equipment. There are some 3,000 fuel and control-rod channels.

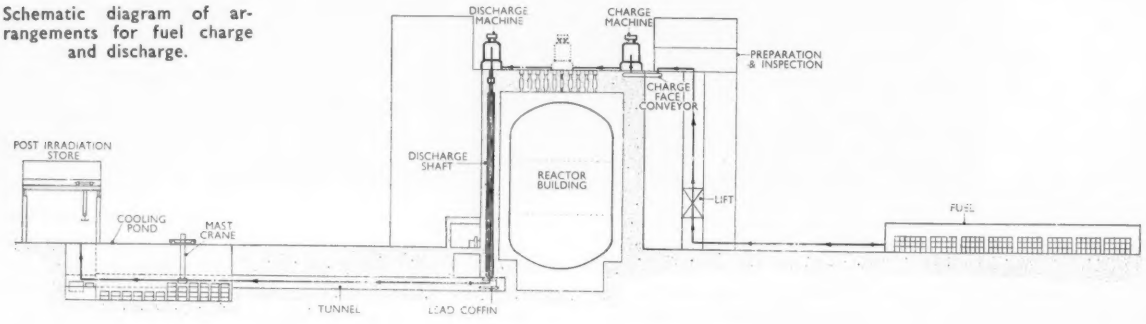
Gas Cooling System

The gas ducting is generally similar to that used at Calder Hall, the diameter being approximately 5 ft. Provision has been made for expansion by means of bellows joints and Genspring supports. Main isolating valves are fitted immediately outside the biological shield, and subsidiary valves are fitted at various points. As at Calder, provision is made for by-passing a certain percentage of the gas for continuous filtration through cyclones and filters, also for drying equipment.

The blowers are of single-stage axial type of B.T.H. design, and are driven by 3,000-h.p. squirrel-cage induction motors, using scoop control fluid couplings to give a speed variation with a range of 5:1. These are operated by electromechanical actuators from the control room. D.C. pony motors are provided for slow-speed emergency operation to give some cooling to the reactor.

The general arrangement of one blower house is shown in the accompanying diagram. An auxiliary blower is provided, as at Calder, for direct circulation of the gas from top to bottom of the pressure vessel, by-passing the heat exchangers, for the release of Wigner growth in the graphite core.

Schematic diagram of arrangements for fuel charge and discharge.

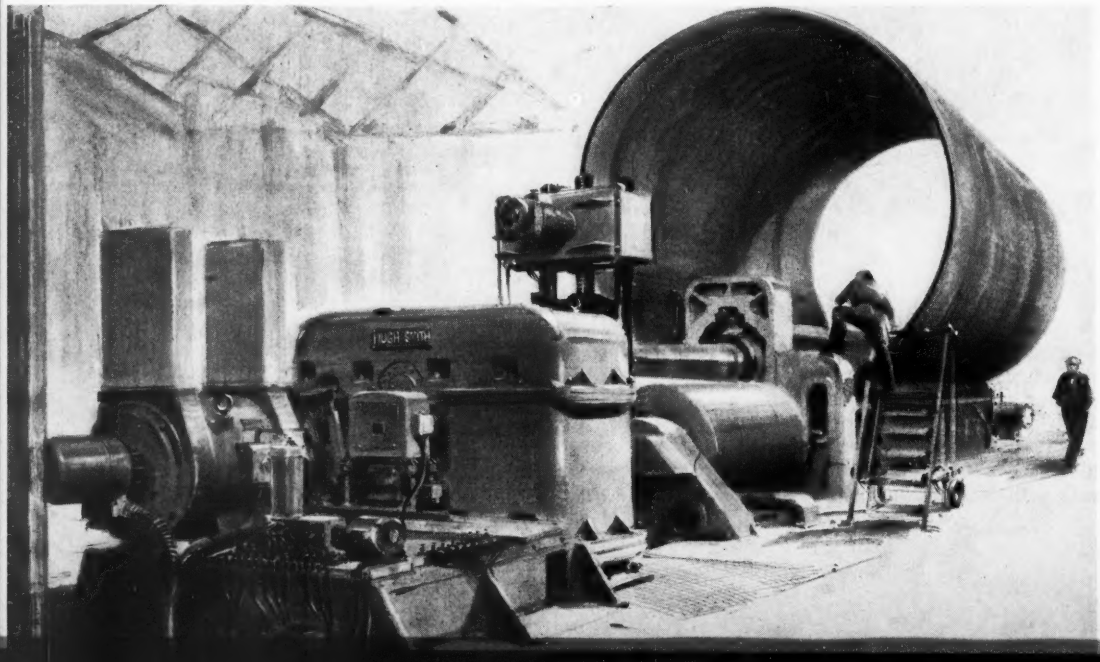


Heat Exchangers

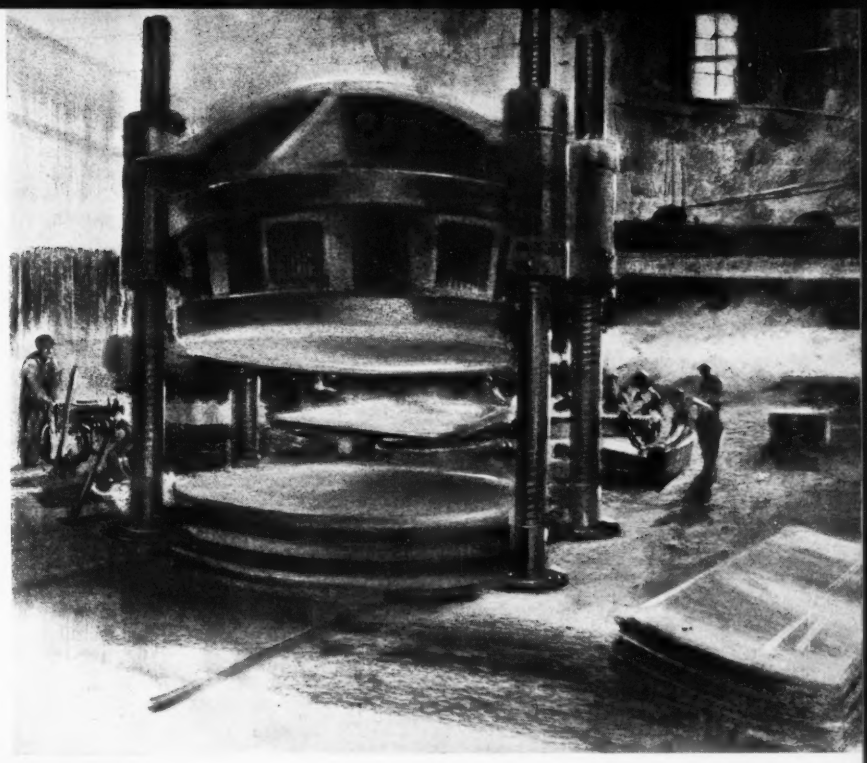
The heat exchangers are similar to those at Calder, but have overall dimensions of 17 ft. 6 in. diameter and 70 ft. high, and are built of $1\frac{1}{8}$-in. plate. The tube sections follow the same general principles as those at Calder, in that they are arranged for dual-pressure steam cycle and use finned tubes for generating and economizer sections and plain tubes for the superheater. As would be expected, however, the design differs widely in actual details. Each heat exchanger complete weighs about 400 tons.

Fuel-element Changing

As previously stated, the fuel elements are capable of being changed on load. As can be seen from the diagram, fuel is stored in the pre-irradiation store in its original boxes and is delivered by trolley in the ordinary way to the reactor lift. At the top of the reactor building are unpacking and preparation rooms, from which the fuel



Rolling heat exchanger sections in the large rolls at John Thompson's Wolverhampton works.



Pressing 3-in. plates in spherical dies for the domed ends of the pressure vessel.

(Below) Training site welders.

is taken to the charge face of the reactor and inserted into the loading machine by a short conveyor. The loading machines, of which there are three, are so designed that no portion is permanently left exposed to irradiation inside the reactor and they are heavily shielded in order to safeguard the operator from the radiation of the spent fuel elements. These are stored in the discharge machine until it is moved over to the discharge shaft into a lead-lined coffin with a self-closing lid, the loading of the elements being under continuous observation by means of a periscope. The coffin is mounted on a trolley and moves down a tunnel and is then lifted over into the cooling pond. The irradiated elements are stored for the necessary delay period after which they are transferred to a shielded vehicle for shipment to Windscale.

Control

One control room deals with the entire station, providing centralized control for both reactors and for the electrical equipment. Flexibility is the keynote and, although each reactor is intended for independent operation, it will be possible to run the turbines normally associated with one reactor from the other one as required, thus giving maximum convenience for maintenance.

Burst-slug Detection

The primary portion of this, i.e., the actual gas-sampling equipment, is of similar design to that provided at Calder Hall. Instead of rate meters and recorders, however, the output from the scintillation counter is fed through a scaler to computer equipment generally as described in *Nuclear Engineering* for February (page 77).

Works Progress

When one considers that contracts for these power stations were only placed in November and that site work only commenced in January, one might be forgiven for assuming that the progress made both on site and in actual manufacturing would be inconsiderable. Such, however, is by no means the case, to judge from recent visits to the site and to the John Thompson Group works at Wolverhampton.

Progress at the site is discussed in another section. At the works considerable progress has been made in the shaping of the plates for the pressure vessel. Accuracy is of considerable importance in this matter, since the amount of weld metal to be deposited (and thus the construction time), to say nothing of the weld quality, could be adversely affected if rough-and-ready methods were tolerated. Since the ends of the vessel are not true hemispheres, the shaping of the plates in a heavy press has involved the use of two distinct sets of dies. The central and petal plates, which lie on the truly spherical portion, can be pressed with a standard spherical die, irrespective of their shape; the knuckle plates, which involve a sharper radius in one plane, have been pressed in special dies fabricated for the purpose. Each plate weighs approximately 3 tons.

Edge preparation by conventional planing methods was not possible owing to the shape of the plates and is being carried out by flame cutting using a template and a magnetic traction head.

The template has been made in the Ordnance division of the associated company, John Thompson (Conveyors) Ltd. This division is normally engaged in precision work in connection with gun mountings and predictors, and its particular skill is also being utilized in the production of the guide tubes and their associated mechanisms for the fuel-element charge and discharge gear, a deep pit in the floor serving as a mock-up for the reactor during the tests and adjustments during development work.

Welding, it is considered, will not be a major bottleneck in construction and the welding force for a job of this magnitude will be comparatively small. Nevertheless, it is absolutely essential that this should be composed of picked men, and a course of intensive instruction and testing is being carried out with a number of men who are already skilled welders to ensure beyond any shadow of doubt that each one is up to the vigorous standards demanded by Class 1 site welding on plates of this thickness.

Civil Engineering Work at Berkeley

THE Berkeley power station is situated on the banks of the River Severn about 1½ miles from the village of Berkeley, Gloucestershire. The layout is such that the turbine house and the two reactor buildings are arranged in a symmetrical pattern about a centre line, with the smaller ancillary units functionally disposed about the main units. The site is divided by an "active area" fence into two distinct areas. One encloses all the buildings connected with the nuclear portion of the station and the other encloses the conventional power-station buildings, such as the turbine hall, administration block and workshops. These areas approximately define the responsibilities of the two civil engineering contractors concerned. John Laing and Son Ltd. are responsible for the construction of the reactors, erection of the heat exchangers and associated works, such as the cooling ponds, fuel-element store, CO_2 store and active-waste treatment plant. Balfour, Beatty and Co. Ltd. are responsible for the turbine hall, administration block, workshops, cooling-water services and sewage works. W. S. Atkins and Partners are the consulting engineers to A.E.I.-John Thompson.

The first essential was to work a way into the site and the County Council built a new 22-ft. concrete road from Berkeley to the site, involving the building of a bridge across the Berkeley Pill, a small stream.

First Tasks

Work began on the site on Monday, January 7, the immediate tasks being to set up site offices, gain access to No. 1 reactor site (that nearest the river) and to begin work on the labour camp. Arrangements also had to be made for the laying on of essential services, such as water, electricity and telephones, and the site engineers were unanimous in their praise for the enthusiasm, speed and efficiency with which the undertakings co-operated.

Four 20-cu.-yd. and two 15-cu.-yd. scrapers began work the same day stripping top soil from areas to be covered by roads and foundations. The top soil is being stored so that it can be spread over areas to be re-grassed, but care has to be taken not to build up too high mounds which might interfere with sighting of the Severn navigation beacons. Another problem in this connection will arise when the floodlighting for night work, now being installed, comes into use. This is being considered by the contractors and the river authorities and shipping interests concerned.

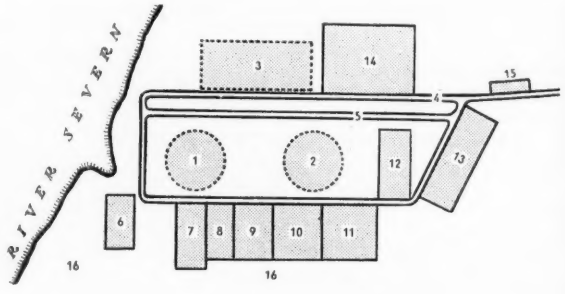
The main road through the site and various access roads are being built up from quarry waste, some thousands of tons having already been laid: these roads will gradually be built up to the finished height as work progresses.

The detailed programme for the first 12 weeks from the commencing date envisages the completion of the excavations for the foundations of No. 1 reactor, site offices and much of the labour camp and canteen facilities. The camp is being constructed, initially, for 600 workers, with bungalow married quarters.

The programme for No. 1 reactor calls for the excavation of a hole approximately 35 ft. deep and 250 ft. in diameter, necessitating the removal of some 85,000 cu. yd. of soil: because the ground slopes away from the river, somewhat less will need be dug from No. 2 site.

When we visited the site on February 6, the contractors were ahead of schedule, in spite of several days of very heavy rain: about half of No. 1 reactor site excavation had been completed. Initially, the hole was opened out with an access ramp excavated by a Lima 802 drag-line and two 43 RB excavators, the ramp now being maintained at a gradient of about 1 in 12. At the time of our visit, excavation was being carried out by four 43 RBs loading into a fleet of 19 Euclid rear-dump trucks of 15 tons capacity each, the Lima drag-line assisted by Caterpillar tractors with dozer blades maintaining the ramp. Work on the turbine hall site has not yet begun, but it will involve the removal of some 130,000 cu. yd. of soil to a maximum depth of 45 ft.

Most of the site lies below the flood level of the River Severn and therefore the site will eventually be filled to 2 ft. above this level. There are considerable quantities of groundwater to be reckoned with, and a series of boreholes, which will contain submersible pumps, is being drilled round the reactor and turbine hall sites. Round the



1. Reactor No. 1
2. Reactor No. 2
3. Turbine hall
4. Main access road
5. Access roads
6. Plate and heavy engineering
7. Pressure vessel assembly (graphite store later)
8. Brick store
9. Concrete-mixing plant
10. Precasting yard
11. Reinforcement bending
12. Heat-exchanger assembly
13. Vehicle park
14. Labour camp
15. Temporary site offices
16. Spoil dumps

Preliminary site organizational layout.

Mucking-out for the foundations of No. 1 reactor.

turbine hall the bore-holes extend to a depth of 135 ft. and round the reactors to 75 ft. Beresford 7½-in., 2,500-g.p.h. electric submersible pumps will be used, in the main, with some larger ones of 8,000-g.p.h. capacity at certain points. The drilling and installation of the dewatering system is being done by John Thom Ltd.

Other work in hand when we visited the site only four weeks after the commencement of operations included the pressure-vessel assembly area, erection of one concrete-batching plant and the labour camp. Many of these camp buildings and bungalows were completed and nearing completion. The labour force at the time was about 550, being drawn largely from Bristol, Stroud and Gloucester. It is expected that at the peak of construction the labour force will be about 2,000. Conigre Pill, a main drainage ditch with tidal outlet, has been diverted; a diversion channel, 650 yd. long, having been dug by drag-lines.

The design of the Berkeley power station has been dealt with on previous pages, but some of the civil engineering aspects are worth considering.

A concrete batching and mixing plant is being set up midway between and south of the two reactors. This is a Winget plant feeding two 2-cu.-yd. mixers. Various grades of aggregate are raised into storage hoppers feeding on to an enclosed conveyor system, allowing any particular grade to be selected at will. The aggregate is then conveyed into the hoppers of the batching plant. Sand is similarly raised to the plant and cement is fed in from silos by bucket conveyor. Concrete will be pumped to the job. Where density is of extreme importance, as in the biological shield, the pumped concrete will go to skips, from which it will be placed mechanically and then vibrated. A batching plant is to be used by Balfour, Beatty on their part of the contract, with the difference that the cement will be raised to the batching plant by compressed air.

Each reactor will be housed in a building 170 ft. high. The main raft, together with the reactor foundations, will be 21 ft. thick and will be placed in 3-ft. lifts. The bearing pressure of the reactor on the raft will be of the order of 2.5 tons per sq. ft.

The main biological shield will be of reinforced concrete 8 ft. 6 in. thick. The top shield will be about 10 ft. 6 in. thick but, owing to control-rod equipment voidages, the effective thickness will be 8 ft. A 3-in. mild steel plate will cover the upper surface of the top shield. The thermal shield is a double-walled structure with an air gap allowing induced-draught cooling of the shields. The outer steel wall forms the permanent shuttering for the biological shield: the external shuttering is of timber.

Steel plate ½ in. thick will be used for the side wall shuttering and ⅜ in. for the top shield. The inner wall will be ½ in. steel on the bottom and sides and 5 1/16 in. at the top. Between these walls, the air gap varies from 1½ in. at the sides to 2 in. at top, 4 in. at bottom and 4½ in. at the shoulders. The weight of the pressure vessel is carried, via special rocking feet, on 14 in. R.S.J.s in 12 in. of concrete on the main foundations.

Euclid dumpers removing spoil from the reactor site.

Drawings by staff artist John Crawley.

An interesting feature will be the method of erection of the thermal shield, co-ordinated with the placing of the biological shield concrete and the erection of the pressure vessel. This arrangement provides for the assembly of the bottom dome of the pressure vessel in a special erection area adjacent to the reactor. It will then be slid on rollers along a ramp into position on its foundations. The building up of the double-walled thermal shield will then progress ahead of the *in situ* construction of the pressure vessel and the placing of the concrete in lifts. A spider of 8 in. × 6 in. steel columns at 15-ft. centres holds the thermal shield plates in position, the panels being dropped in and welded. At a height of 32 ft., a special roof will be lowered on to provide a weatherproof, heated room in which assemblers and welders can work, building up the pressure vessel with 18 ft. × 6 ft. × 3 in. plates. As work progresses, the roof will be raised on the growing thermal shield: it can also be lifted off for lowering in materials for the pressure vessel.

Heat exchangers will be assembled on a special site and run into the erecting position on trolleys. Two post cranes, 96 ft. high and placed at 27-ft. centres, will be used for lifting the heat exchanger vessels from the horizontal position to the vertical position, the winches lifting from a girdle round the vessel.

One of the major problems of this station is the cooling-water inlet and outfall in the River Severn and the associated tidal and navigational considerations.

The contractors have already carried out test driving of steel piles, the results of which have shown that piles can be driven without undue difficulty. Tidal investigations were carried out some time ago for the Central Electricity Authority by Rendell, Palmer and Tritton, consulting engineers. For these investigations a scale tidal model was built by the Central Laboratory of George Wimpey and Co. Ltd. A marine survey, using echo-sounding equipment, is also to be carried out by A.E.I.

The design calls for the intake works to be situated well out into the river, with the outlet upstream and closer inshore. To prevent mixing of the comparatively hot outlet water with the inlet, a baffle wall dividing these works will have to be built. Because the river is tidal this wall will extend some distance up and downstream from the intake.

The baffle wall will be of box-pile construction, driven from a derrick on gabbarts running on rails. The intake comprises two screen chambers feeding through two or four tunnels to the pumphouse. The high-water spring tide is +25 ft. and low water −5 ft. The sill level will be at −16 ft., giving a minimum depth of water of 11 ft. A certain amount of dredging in the vicinity will have to be undertaken. At present the bed level is between 0 and −10 ft. and the channel will be dredged down to −17 ft.

La Centrale Nucléaire de Berkeley

La centrale de Berkeley, conçue par le consortium A.E.I.-John Thompson suit les principes établis à Calder Hall de plus près que les centrales de Bradwell ou écossaises, les différences principales consistant en l'augmentation de la capacité, l'emploi de 8 échangeurs de chaleur au lieu de 4 par réacteur, la prévision de changements de combustible en charge, l'emploi de souffleurs axiaux au lieu de radiaux, et l'application des techniques de la machine à calculer pour le contrôle des gaz. Bien que le contrat n'ait été placé qu'en novembre dernier et que les travaux sur le chantier n'aient commencé qu'en janvier, des progrès considérables ont déjà été effectués.

Das Berkeley Atomkraftwerk

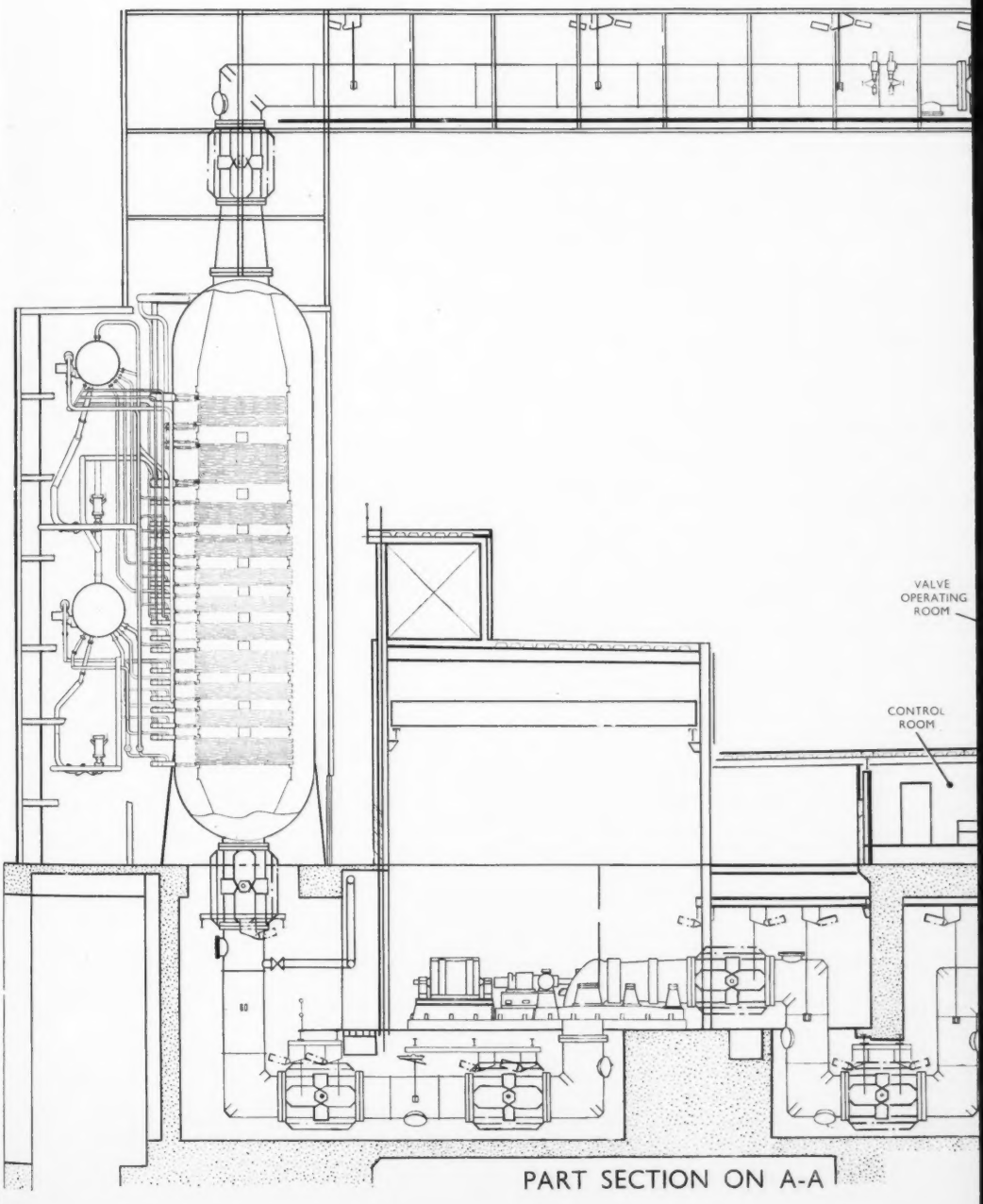
Das Berkeley Kraftwerk, das von dem A.E.I.-John Thompson entworfen wurde, folgt viel mehr den Grundlagen, die in Calder Hall aufgestellt wurden, als das Werk in Bradwell sowohl, wie auch das Werk in Schottland. Die Haupt-Abweichungen betreffen die vergrösserte Kapazität, die Verwendung von 8 Wärme-Austauschern anstatt 4 je Reaktor, die Vornahme des Brennstoff Wechsels unter Belastung, die Verwendung von achsialen Gebläsen anstatt der radialen, und die Anwendung der Technik der elektronischen Rechenmaschinen für die Gas-Ueberwachung. Obwohl der Kontrakt erst im letzten November abgeschlossen wurde, und die Arbeit auf der Baustelle erst im Januar begonnen wurde, ist doch bereits ein erheblicher Fortschritt zu verzeichnen.

La Central de Fuerza Nuclear de Berkeley

La central de fuerza de Berkeley, diseñada por el Consorcio A.E.I.-John Thompson sigue los principios establecidos en Calder Hall más estrechamente que las Centrales de Bradwell o las escocesas, las características principales consisten en la capacidad aumentada, el uso de 8 cambiadores de calor en lugar de 4 por reactor, la provisión de cambio de combustible en carga, y la aplicación de las técnicas de computador para la supervisión de gases. Aunque el contrato fué colocado solamente en noviembre último, y se comenzó el trabajo en sitio solamente en enero, ya se han hecho progresos considerables.

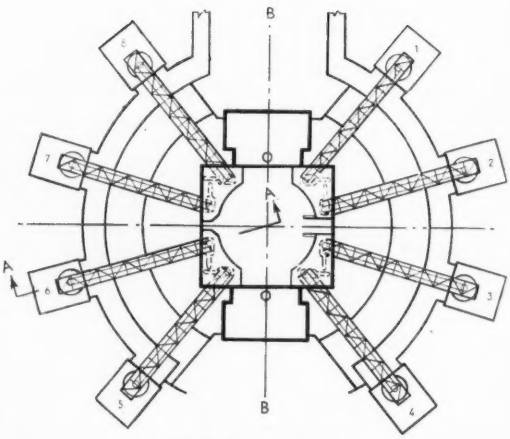
The World's Reactors

No. 10—BERKELEY POWER STATION

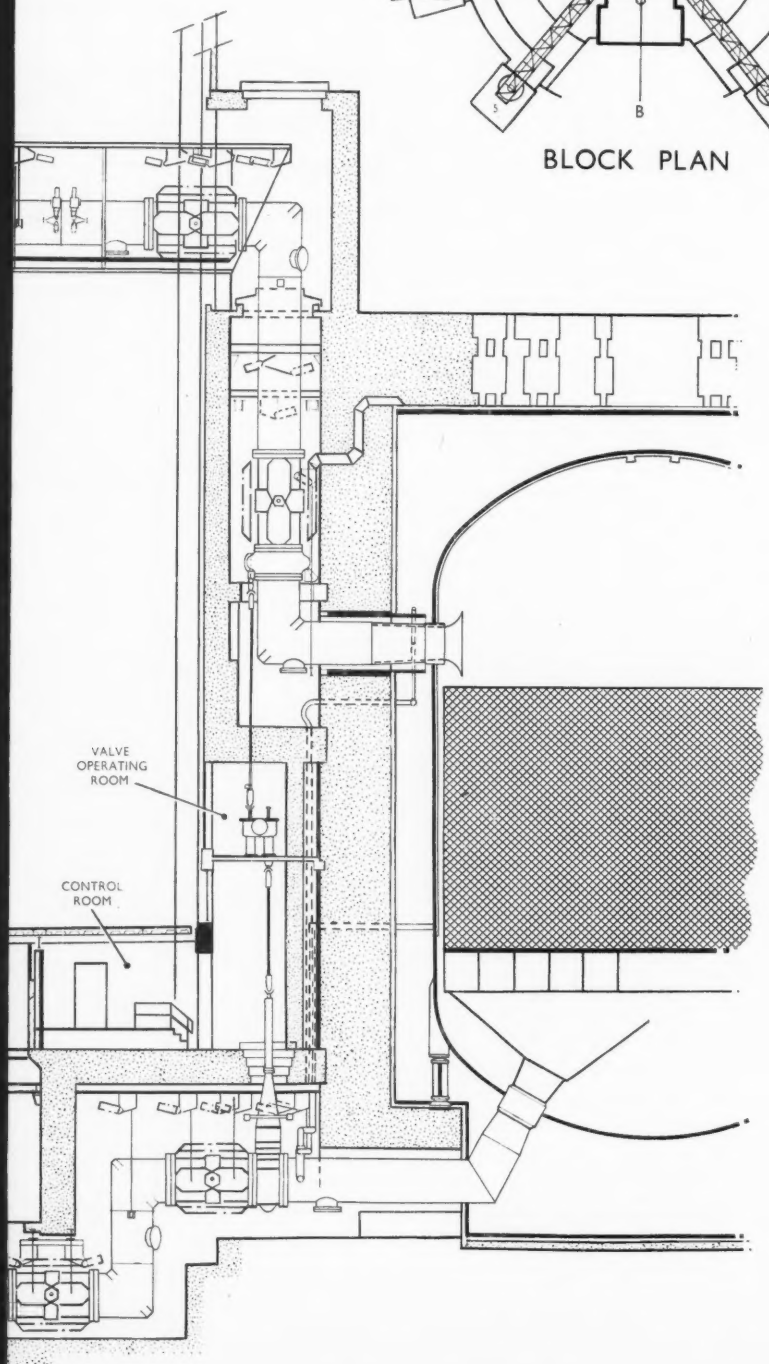


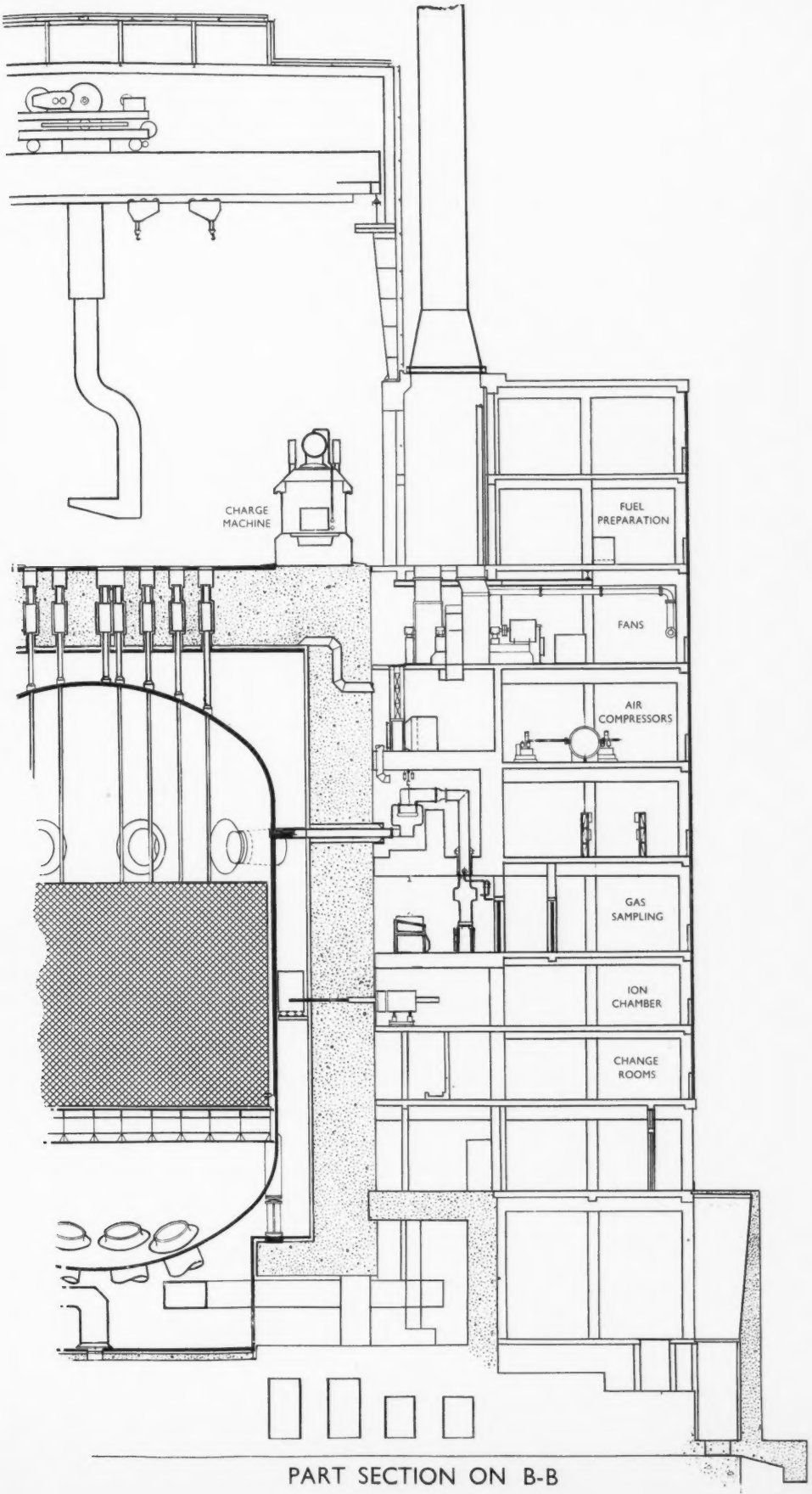
PART SECTION ON A-A

ON



BLOCK PLAN





PART SECTION ON B-B

The World's Reactors

No. 10—BERKELEY POWER STATION

TYPE: Thermal heterogeneous.

PURPOSE: Power production.

LOCATION: Berkeley, Gloucestershire.

OPERATION:
No. 1 reactor: mid-1960.
No. 2 reactor: early 1961.
Ground broken: January 7, 1957.

CAPACITY:
Maximum continuous electrical rating: 340 MW and four turbo-alternator sets.
Guaranteed electrical output: 275 MW.
Distribution to grid: 132 kV.
Internal distribution: 6.6 kV, 415 V and 240 V
Reactor heat rating: 550 MW.

FUEL:
Natural uranium as rods.
Weight of U per reactor: 250 tonnes.
Number of fuel-element channels: 3,000.

CANNING:
Magnesium alloy, Magnox A12.
Method of support: graphite struts with zircon

MODERATOR:
Graphite.
Core size: 42 ft. diameter, 24 ft. high.
Overall size, including reflector: 48 ft. across regular polygon prism, 30 ft. high.
Total weight of graphite per reactor: 2,000 ton
Graphite support: ball bearings on diagrid 4 ft

LATTICE: Regular square, 8.16-in. pitch.

PRESSURE VESSEL:
Mild steel.
Shape and dimensions: cylinder, 50 ft. diamet
Thickness: 3 in.
Maximum internal working pressure: 125 p.s.i.
Inner shell: $\frac{1}{4}$-in. plate.

COOLANT:
Carbon dioxide.
Inlet temperature: 320° F.
Outlet temperature: 662° F.
Flow: 22.3 × 10^6 lb./hr.
Number of ducts: eight inlet, eight outlet per r
Duct diameter: 5 ft.

PUMPING:
Eight single-stage axial blowers per reactor.
Drive: a.c. squirrel-cage induction motors with V control fluid couplings.
Circulator input: 3,000 b.h.p.
Running speed: 2,900 r.p.m.
Speed control range: 5 : 1.
Electrical power consumption: 17 MW per react

CONTROL: Number of channels: 150 per reactor.

SHIELDING:
Thermal: mild steel.
construction: double wall, with air gap
sides: outer $\frac{1}{2}$ in., inner $\frac{1}{2}$ in., air gap
top: outer $\frac{1}{8}$ in., inner $5\frac{1}{16}$ in., air gap
bottom: outer $\frac{1}{2}$ in., inner 4 in., air g shoulders).
cooling: air, induced draught.
Biological: reinforced concrete.
sides: 8 ft. 6 in.
top: 10 ft. (effective thickness 8 ft.) top plate.

tors

TATION

g: 340 MW from two reactors

W.

and 240 V d.c.

s.
,000.

with zirconium end brackets.

h.
ft. across corners of 32-sided

r: 2,000 tons.
diagrid 4 ft. 7 in. deep.

ft. diameter, 80 ft. high.

125 p.s.i.

outlet per reactor.

reactor.
tors with Vulcan-Sinclair scoop

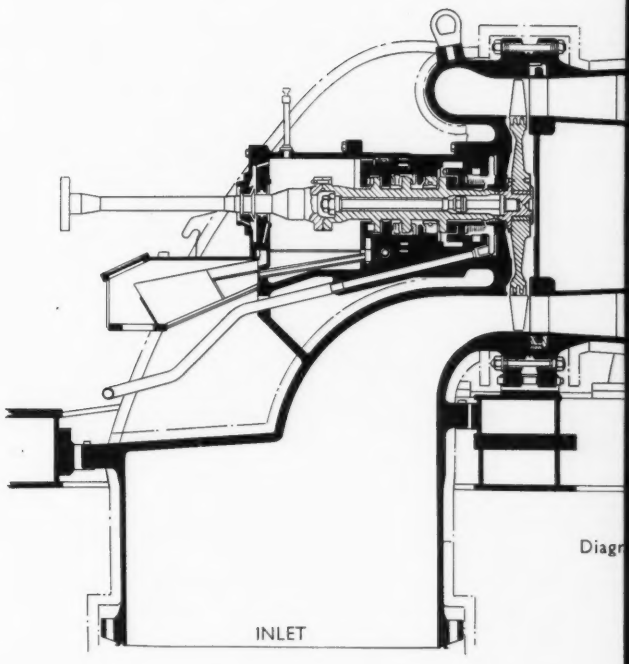
W per reactor.

r.

with air gap between.
in., air gap 1½ in.
in., air gap 2 in.
4 in., air gap 4 in. (4½ in. at

ht.

kness 8 ft.) with 3-in. mild steel



Diagr

HEAT EXCHANGERS:

Number per reactor: eight.
Main shell: 17 ft. 6 in. O.D., 70 ft. high
Elements: finned-tube boiler and econ
superheater sections.
Inlet gas temperature: 660°F.
Outlet gas temperature: 318°F.
H.P. steam flow rate: 140,000 lb./hr.
H.P. steam temperature: 612°F.
H.P. steam pressure: 320 p.s.i.a.
L.P. steam flow rate: 65,000 lb./hr. pe
L.P. steam temperature: 612°F.
L.P. steam pressure: 77 p.s.i.a.

TURBO-GENERATORS:

Number of sets per station: four horiz
compound mixed-pressure impulse ty
Continuous maximum rating per set: 8
Speed: 3,000 r.p.m.
Generated voltage: 11.8 kV.
Cooling: hydrogen.

DESIGN AND CONSTRUCTION

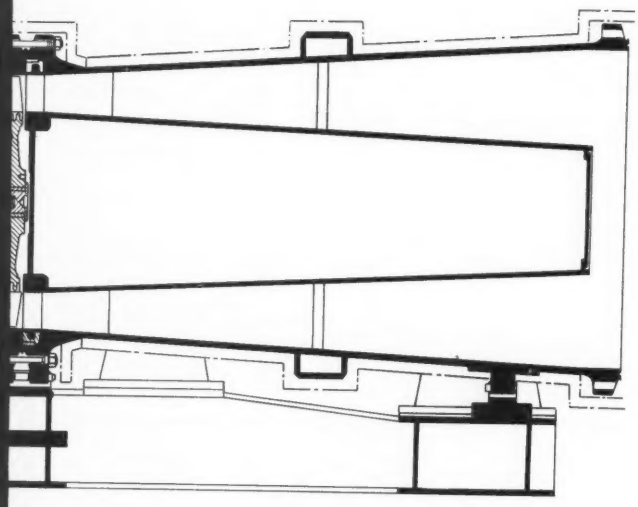
A.E.I.-John Thompson Nuclear Energy Co. Ltd.
comprising: Associated Electrical Industries Ltd.
John Thompson Ltd.
Balfour, Beatty and Co. Ltd.
John Laing and Son Ltd.

CONSULTING ENGINEER TO A.E.I.-JOHN THOMPSON

W. S. Atkins and Partners.

Data sheets in this series already published in "Nuclear Engineeri

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. RUSSIAN 5 MW (November, 1956)
No. 8. DIDO (January, 1957)
No. 9. THE SOUTH OF SCOTLAND ELECTRICITY (February, 1957)



Diagrammatic section of B.T.H. single-stage axial blower unit (dotted outline represents lagging).

, 70 ft. high; thickness 1⅛ in.
r and economizer sections; plain tube

F.
8°F.
000 lb./hr. per exchanger.
2°F.
.s.i.a.
0 lb./hr. per exchanger.
2°F.
.a.

: four horizontal close-coupled tandem impulse type.
per set: 85 MW.

V.

r Engineering" are:

r, 1956)

ECTRICITY BOARD STATION

Nuclear Reactors for Industrial Use

by

D. J. ALLEN-WILLIAMS, M.A., Ph.D., A.M.I.C.E., A.M.I.E.E.,

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Chief research engineer and senior projects engineer (thermodynamics) respectively, Davey, Paxman and Co. Ltd.

Consideration is being given by a number of countries to the industrial utilization of heat and steam produced by reactor systems. In an attempt to evaluate the feasibility, the authors give cost estimates for suitable types of reactor.

TRADITIONAL fuel costs are rising rapidly and are likely to continue to do so, whilst fuel reserves are falling. In Britain, production of coal is not keeping pace with increasing demand: this has led to a policy of increased oil-burning, making users in Britain dependent on imports of fuel oil. At the moment discoveries of proved reserves of oil are believed to be gaining slightly on consumption, but the producing areas are political danger spots. It is therefore imperative that ways and means be sought of improving the nation's heat economy.

At present some 200 million tons of coal are burnt annually in Britain. 40 million tons are burnt in large-scale power stations generating electricity equivalent to the energy content of about 12 million tons. The energy from the remaining 28 million tons is being lost to the atmosphere, to rivers, or to the sea.

Industrial users do not convert to electricity or mechanical work a comparable amount of the 42 million tons they burn; but some also generate steam which may be necessary for carrying out their particular manufacturing processes, thus being able to claim a better overall thermal efficiency. Very often close examination discloses that much of the heat is unnecessarily rejected later on in the process. The iron and steel industries use 24 million tons of coal and coke; the railways burn 13 million tons at an average efficiency below 10%; collieries take 9 million tons; and miscellaneous users burn some 28 million tons. Of the 42 million tons burnt in homes, an incredible amount of the energy is thrown away (perhaps that of 30 million tons).

It is therefore obvious that steps must be taken to improve the efficiency of conversion of coal and oil to useful work, or to find some suitable new fuel to replace them. It has been said that, considering marginal coal costs, it is probably worth while spending up to £100 of capital to save the consumption of 1 ton of coal per annum.

This article suggests some practical applications for the direct use of nuclear energy and estimates how much coal or oil might be saved at what cost by the use of nuclear fuels for steam generation.

Present Reactor Systems

Throughout the world, about 50 nuclear reactors have been constructed and put into operation. They are essentially producers of varying amounts of heat at temperatures ranging from 60°F to 660°F. At present the physical properties of construction materials limit the temperatures that can be safely realized. Projects are under consideration for reactor systems in which the coolant will reach temperatures approaching 2,000°F, but they will require many years of development.

At this stage, however, it is advisable to confine our attention to reactor systems already in existence, or known to be feasible, and their possible uses for industrial processes, including space-heating. Admittedly, heat energy is more efficiently converted to work the higher the temperature at which it is released, but there is still an unfulfilled demand for apparatus capable of producing industrial heat and steam. Not everybody wishes to drive an engine from their fuel.

Both the U.K. Atomic Energy Authority and the U.S. Atomic Energy Commission have considered it worth reclaiming some small part of the immense amount of heat normally discharged from their production and research reactors to the atmosphere or rivers. They have, in fact, installed small district-heating systems for office blocks and laboratory buildings, and thus save some thousands of tons of coal annually.

Sweden is planning two reactors for district heating: one is to produce 90 MW of heat (a rating of approximately 300,000 lb. of steam per hour), the second is to produce 71 MW of heat and 13 MW of electrical power, although this later development is considered more difficult, as somewhat higher temperatures and pressures are involved.

Norway has planned a 10-MW reactor to be used partly for power and partly for steam processing in the paper pulp industry. In Finland, the Atomic Power Company is also considering the application of nuclear power for steam generation for use in the wood pulp industry.

In Britain, a quoted price for 100 p.s.i. steam generated by a Calder Hall type is 3s. 8d. per 1,000 lb. (approx. 10^6 B.Th.U.). Admittedly it is unlikely that an industrial user could consume the 1,000,000 lb. per hour generated at Calder Hall, but in medium-sized industrial installations (say 100,000 lb. per hour) steam from conventional boilers costs upwards of 6s. per million B.Th.U. and there are factory installations in this country generating 500,000 lb. per hour in a single unit.

In Europe, by far the greater part of all energy is consumed directly in the form of heat. In the U.S.A., about 30% of the total consumption of energy is used for space heat and about 10% for process heat. Although it may still be too early to calculate production costs for nuclear energy with any accuracy, it is believed that these costs are of an order of magnitude comparable with those of the conventional forms of energy. As the latter vary considerably from one region to another, it may well be that power produced from nuclear energy would already be economically advantageous in certain regions. Dr. M. D. Wood has already discussed one aspect of this problem in *Nuclear Engineering* for November, 1956.

It is generally thought that the cost of nuclear energy will fall in the coming years, but it would be a mistake to expect the cost to fall low enough for nuclear energy to supersede other forms of energy. The high capital costs envisaged

suggest that only high load factor and relatively large installations will be economically feasible for some time to come. Even so, it is likely that some industrial needs exist today in places which are not necessarily remote, where fuel costs are high and demands for heat are large. These applications will only be found if industry outside the specific field of the various Authorities' programmes becomes familiar with, and in turn confident of, nuclear heat.

Possible Applications of Nuclear Heat

It is difficult to point to assured economic advantage today for nuclear sources of heat for conventional process steam. Initial applications may be expected to be in large plants where transport costs favour taking nuclear fuel (rather than conventional fuels) to raw materials, or where nuclear heat offers unique advantages: e.g., no ash which would require storage, handling and disposal; no need for oxygen to promote the reaction; and the fact that the appropriate coolant or working medium can be kept "clean".

The McKinney report suggests the processing of the phosphate rocks of Idaho into fertilizer at the quarries, the development of ores in Central and South America, and possibly the opening up of new mines in the polar regions as future operations for which nuclear power should be seriously considered. The development by the Aluminium Company of Canada at Kemano is quoted as an example of the efforts that can be justified in order to avoid long transport of bulk ore. One of the largest users of process heat is the pulp and paper industry, in which 5% of the total value of the product is in the cost of fuel and about 2% in the cost of electricity consumed.

In fact, the ability to provide power and heat independent of bulk transportation of fuel issues a challenge to many refining and processing industries to reconsider the best location for their plants in relation to the site of production of the raw material.

Space heating has already been mentioned as a possibility. This may become economical for installations requiring upwards of, say, 25 million B.Th.U. per hour. The use of nuclear steam in district-heating schemes should be investigated, especially for cities of high population density in cold areas.

Studies on the distillation of salt water in the U.S.A. were not very favourable; but large-scale distillation processes in other parts of the world might prove attractive. It is also possible that distillation as a means of separating liquids from solids or liquids from liquids might be made economical where large volumes have to be handled. In a country's atomic energy development programme it may be both economical and appropriate to reduce the demand on fossil fuels by using nuclear heat to carry out special processes such as the separation of isotopes required for that programme.

The McKinney report (Volume 2) also lists as being under consideration the following possible applications for nuclear heat:

(1) Nitrogen fixation.

(2) Acetylene production.

(3) Production of hydrocyanic acid from methane and ammonia.

(4) Copper smelting.

(5) Smelting of iron near the source of ore.

(6) In the higher temperature range, apart from reactors to work with gas turbines, the U.S.A.E.C. is already sponsoring a project for the use of nuclear energy to react coal with steam at temperatures around 2,500°F, and a private American company is studying the process as a potential source of hydrogen for ammonia synthesis.

To make a reactor installation economically attractive, every opportunity should be taken of making the reactor provide as many services as possible. For example, a reactor providing radiations for sterilization and pasteurization of food products, or polymerization and catalysis of chemicals—services peculiar to a reactor—might also be used for space heating.

"In the distant future", to quote the McKinney report, Volume 2, ". . . . (one can see) complex and highly integrated chemical plants in which endothermic reactions proceed with nuclear heat, perhaps catalysed by nuclear radiations. By-product power for operating the plant's equipment would be derived from the nuclear-fired process-steam boilers, and fission products in such a fully efficient complex would be recovered for sale. . . . Of course, process control in such a plant would be effected whenever possible by the use of tracers and other radio-active means."

To return from such an idealized picture of a highly efficient future chemical plant to present-day possibilities, the maximum plausible demand for process heat, according to Putnam, is likely to increase approximately five times between A.D. 1950 and 2000. If this growth occurred linearly, it could mean a need for some 2,000 new 50-MW process heat boilers annually, for example.

Because of the necessity for having a minimum "critical" amount of fuel to make the reactor operate, small plants will be out of the question. To set the scale, in a design of reactor producing 20 MW heat (68 million B.Th.U. per hour), the containing pressure vessel would be 5 ft. 8 in. diameter by 23 ft. high, with a core size of 4 ft. diameter by 4 ft. high. A very large hotel might require 3.4 million B.Th.U. per hour. Our own works loads in winter (mainly space heating) total about 22 million B.Th.U. per hour.

Economics of Reactor Operation

At the 1955 Geneva Conference figures were quoted for an American prototype boiling-water reactor (EBWR). These figures were used by the McKinney Committee to estimate the cost of steam heat from such a reactor

TABLE I—ANNUAL AND HEAT COSTS FOR A REACTOR GIVING 20 MW AND 40 MW OF STEAM HEAT

Investment: Capital cost of plant: £500,000.
Fuel investment in plant: £338,000 (including "cooling" after discharge)
(Price of natural uranium: £20,000 per tonne. Price of uranium 235: £12,000 per kg)

Reactor Heat Rating (in B.Th.U. per hour)	20 MW (68.2×10^6)		40 MW (136×10^6)	
Costs	Annual: £	pence per 10^6 B.Th.U.	Annual: £	pence per 10^6 B.Th.U.
Capital	75,000	50.2	75,000	25.1
Fuel rental	16,900	11.3	16,900	5.7
Operation (labour, etc.)	12,600	8.4	12,600	4.2
Fuel fissioned	28,900	19.3	57,800	19.3
Separation of natural uranium Credit for plutonium produced	} balance out	—	} balance out	—
Separation of U^{235} from type-B elements	6,000	4.0	12,000	4.0
Fabrication of new fuel elements	9,000	6.0	18,000	6.0
Total fuel bill	43,900	29.3	87,800	29.3
Total cost	£148,400	99.2d.	£192,300	64.3d.

stripped of its generating equipment and experimental apparatus. Based on what has been published in this context and allowing for the different prices of nuclear fuels and capital equipment in the United Kingdom, it is possible to estimate the order of cost of obtaining heat as steam from a similar reactor.

The American design was based on a reactor heat output of 20 MW. Later experiments confirmed that this reactor can safely deliver 40 MW heat as steam. The effect of running at those two ratings on steam or heat cost is shown in Table I. These costs are based on the assumption of 60% load factor, 15% per annum capital depreciation, and 5% per annum rent of fuel.

For size, the EBWR reactor is at the low end of the economic range. The Americans built and operated a smaller reactor of this type known as Borax III with a heat rating of about 15 MW (compared with the 40 MW of EBWR) for the experiments on the stability of operation of boiling-water reactors and to determine the order of maximum usable heat flux. Using the same assumptions and the figures quoted at Geneva, or their British equivalents, the cost of heat from this reactor is shown for comparison in Table II.

Some costs have been quoted more recently for the American Army Package Power Reactor system (*Nuclear Engineering*, July, 1956) assuming that it could be worked to give an electrical output of 10 MW at 80% load factor. The thermal efficiency of the saturated steam and generating cycle is about 20%, so the reactor heat rating would have to be 50 MW, a fivefold increase on the present designed heat rating. A British-built equivalent reactor running at this enhanced rating, but with a load factor of 60%, would seem to produce steam at a cost of about 80d. per million B.Th.U.; but, if the reactor were run at the present designed heat rating of only 10 MW, the cost of steam would lie in the region of 150d. to 200d. per million B.Th.U.

The cost of steam per million B.Th.U. from modern British boiler plant of comparable size varies because of regional variations in fuel prices, but normally comes in the range 60d.-85d. to cover capital, fuel and labour costs. Total costs to cover overheads, purchased electricity, water, etc., are from 70d. to 100d. per million B.Th.U.

The costs quoted for the APPR system are too indefinite to be compared with those for conventional boilers, but our figures indicate that this system is unlikely to provide heat at a competitive price unless the reactor can run at a heat rating of about 50 MW (171×10^6 B.Th.U. per hour).

However, the EBWR type (a possible industrial prototype) seems to compete well with modern boiler plant, especially when run at 40 MW. The load factor will apply equally to nuclear or conventional plant; but in cases of load factor as high as 80% the nuclear competition will be even stronger, because the percentage contribution of fuel to total cost is much larger in the conventional case.

Comparative Capital Costs

We have already recorded the opinion, expressed at a recent technical meeting, that when marginal coal costs are considered it is probably worth while spending up to £100 of capital to save the consumption of one ton of coal per annum. In Table III the capital costs of nuclear and conventional-fuelled plant per ton-year of coal burnt in the conventional plant are compared. The cost of nuclear boiler plant is taken from the figures quoted in Table I for the boiling-water reactor working at a heat rate of 136×10^6 B.Th.U. per hour (40 MW).

TABLE II—ANNUAL AND HEAT COSTS FOR A SMALL 12 MW REACTOR WITH FULLY ENRICHED FUEL

Investment: Capital cost of plant: £100,000
Fuel investment: £212,000 (including spent fuel in "cooling" tank)

Reactor Heat Rating (in B.Th.U. per hour)	12 MW (41×10^6)	
Costs	Annual: £	pence per 10^6 B.Th.U.
Capital	15,000	16.7
Fuel rental	10,600	11.8
Operation:	6,300	7.0
Fuel fissioned	38,800	43.3
Chemical separation of U 235	31,800	35.4
Credit for plutonium	nil	—
Fabrication of new fuel elements	21,200	23.7
Total fuel bill	91,800	102.4
Total cost	£123,700	137.9d.

There are large factories in Britain which could conceivably use nuclear-fired boilers of the Calder Hall type, which cost about £5¼ million each and have a maximum heat rating of 630×10^6 B.Th.U. per hour (185 MW). In this case the capital cost per 1,000 B.Th.U. of steam per hour goes up from £6.1 to £8.3 and the final cost of saving a ton of coal a year goes up from £20.8 to £30.4, which is still less than we as a nation are prepared to pay in order to save coal at our power stations.

From this it is seen that the Government's programme for nuclear power can be justified on the score of saving marginal coal consumption, and large base-load power stations are obviously the first applications where nuclear energy will produce power at a competitive price. But more coal is burnt in industry than in power stations and

TABLE III—CAPITAL COSTS OF NUCLEAR PLANT COMPARED ON A COAL-SAVING BASIS

Power Plant		Heating Plant	
Cost of future coal-fired power stations:	£54.3 per kW installed	Cost of coal-fired boiler plant:	£1.3 per 1,000 B.Th.U. steam/hour
Cost of future nuclear power stations:	£150 per kW installed	Cost of nuclear boiler plant: (including fuel investment)	£6.1 per 1,000 B.Th.U. steam/hour
Future power yield from coal:	2,300 kWh per ton	Coal-fired boiler efficiency:	85% of 12,000 B.Th.U./lb. of coal
Load factor for possible nuclear or coal-fired stations:	75%	Load factor:	60%
Installed capacity equivalent to burning one ton of coal per annum:	0.35 kW	Installed capacity equivalent to burning one ton of coal per annum:	4,350 B.Th.U. steam/hour
Associated capital cost—nuclear:	£52.5	Associated capital cost—nuclear:	£26.5
coal fired:	£19.0	coal fired:	£ 5.7
Increased capital cost of using nuclear energy to save one ton of coal per annum:	£33.5	Increased capital cost of using nuclear energy to save one ton of coal per annum:	£20.8

the cost of saving coal by using nuclear energy directly in many large industrial applications is probably much less.

General Observations

Costs have been given for two simple boiling-water reactors and those for a small pressurized-water system have been mentioned. Other steam-raising reactor systems could have been described: for example, the aqueous homogeneous, which is known to be receiving considerable attention at Harwell; the pressurized-water reactor (PWR and STR) projects in the U.S.A.; the organic liquid-moderated systems, now popularly associated with mercantile marine propulsion schemes but which could be easily adapted to industrial heating schemes possibly without the need to generate steam for transporting the heat.

However, the intention has been to concentrate on systems which already exist, which do not demand high pressures with consequent need for really heavy equipment, which are relatively simple to construct and operate, and which should still be economical on a heat output scale probably considered too small by the planners of large power stations.

In the next two decades or so, there should be considerable amounts of electricity generated in nuclear-fuelled power stations, but it is unlikely that supply will exceed demand and lead to a significant drop in price. In any case, a tremendous technical effort will have to be exerted to fulfil the Government White Paper (1955) plans, let alone to complete the augmented programme recently announced in Parliament.

However, even now private industry could well think about applications for nuclear heat, not least for process steam and space-heating requirements. For example, any company seriously considering the installation of new boilers or replacing old ones in a large factory in 10 years' time should not neglect the implications of the arrival on the scene of this new competitive source of energy. Certain types of reactor already in operation can be considered economically competitive with present-day steam-raising plant, and the capital costs, judged on a coal-saving basis, compete favourably with those envisaged for the nation's nuclear power station programme.

Acknowledgments

We acknowledge drawing largely upon the McKinney report, the Geneva Conference papers, Putnam's careful estimates, Dr. Daniel's 1955 Viscount Nuffield Paper, proceedings of the B.N.E.C. and other sources. We are also indebted to the management of Davey, Paxman and Co. Ltd. for permission to publish this article.

Réacteurs Nucléaires pour les Besoins Industriels

La chaleur produite par des systèmes de réacteur peut être employée au chauffage des espaces, à la production de vapeur, au traitement des minerais et des minéraux, la distillation et divers procédés chimiques. On y cite comme exemples de réacteurs pouvant convenir les systèmes EBWR et APPR et le coût évaluatif de la production de vapeur à partir de ces systèmes pour des fins industrielles y est donné et comparé.

Le coût de la vapeur par million de B.Th.U. (unité thermique anglaise) à partir des installations de chaudières conventionnelles britanniques d'un taux de chauffage équivalent à 10 MW est de l'ordre de 60-85 pence. A ce taux de chauffage les réacteurs nucléaires s'avèrent non économiques à l'heure actuelle.

Un type EBWR, toutefois, avec un taux de chauffage de 40 MW (136×10^6 B.Th.U. par heure) peut produire de la chaleur pour vapeur à raison de 64,3d. par million de B.Th.U. par heur. Un réacteur de Calder Hall produit de la vapeur à un coût de 44d. les 1.000 livres anglaises (environ un million de B.Th.U.) bien qu'il n'y ait que peu d'industries qui puissent consommer le million de livres par heure produites. Il existe, toutefois, des installations d'usines de chaudières conventionnelles en Grande-Bretagne produisant 500.000 livres par heure.

Des tableaux montrent que pour le réacteur à eau bouillante de taux de chauffage de 40 MW, l'augmentation requise de coût en capital pour économiser une tonne de charbon par an peut être de £20,8 pour une installation de chauffage et de £33,5 pour une installation d'énergie.

Kernkraftreaktoren für Industrie Zwecke

Die Wärme, die in Reaktor Systemen entwickelt wird, kann für die Heizung von Räumen benutzt werden, ferner zur Erzeugung von Dampf für Fabrikationsprozesse, zum Verarbeiten von Erzen und Mineralien, zur Destillation und für eine Reihe mannigfacher chemischer Prozesse. Als Beispiele von Reaktor Systemen, die passende Möglichkeiten bieten, werden die Typen EBWR und APPR genannt, und die Kosten, die schätzungsweise bei der Dampf Erzeugung für industrielle Zwecke in Rechnung gestellt werden müssen, werden angegeben und verglichen.

Die Kosten, die zur Dampfentwicklung je Million B.Th.U. (British thermal unit=0,252 kjal) in modernen, jedoch konventionellen Kesselanlagen mit einer Wärme Leistung, die gleich 10 MW angenommen wird, erforderlich sind, sind von der Grössenanordnung 60-85 pence 3-4,20 DM). Es zeigt sich, dass Kernkraftreaktoren mit dieser Leistung vorläufig unwirtschaftlich sind.

Jedoch kann ein Reaktor von Typ EBWR mit einer Wärme Erzeugung von 40 MW (136×10^6 B.Th.U. je Stunde) Heizdampf für 64,3d. (3,20 DM) je Million B.Th.U. je Stunde erzeugen. Ein Calder Hall Reaktor erzeugt Dampf für 44d. (2,25 DM) je 1.000 lb. (ungefähr 1 Million B.Th.U.). Allerdings gibt es nur wenige Industrien, die einen solchen Verbrauch haben, dass 1 Million Pfund Dampf je Stunde erzeugt werden müsste. Immerhin gibt es Fabrik Betriebe mit konventionellen Kesselanlagen in Britannien, wo 500.000 lb je Stunde erzeugt werden.

Die Tafeln zeigen, dass bei 40 MW Wärme Leistung eines "kochendes Wasser"-Reaktors die notwendige Erhöhung der Kapitalkosten, um eine Tonne Kohle pro Jahr zu sparen, für ein Heizwerk £20,8 und für ein Kraftwerk £33,5 betragen können.

Reactores Nucleares para Objetos Industriales

El calor de los sistemas reactores puede ser usado para calefacción, la producción de vapor para procesos, procesado de minerales, distilación y un gran número de procesos químicos. Como ejemplos de reactores posiblemente convenientes, se citan los sistemas EBWR y APPR y se dan y se comparan los costos calculados de la producción de vapor con ellos para objetos industriales.

El costo de vapor por millón de Unidades Térmicas Británicas de instalaciones de calderas británicas modernas convencionales de un regimen térmico equivalente a 10 MW es de unos 60-85 peniques. A este regimen térmico, se demuestra que los reactores nucleares son ineconómicos en la actualidad.

Sin embargo, un tipo EBWR, con un regimen térmico de 40 MW (136×10^6 U.T.B. por hora) puede producir vapor térmico por 64,3d. por millón de U.T.B. por hora. Un reactor en Calder Hall produce vapor a un costo de 44d. por 1.000 lbas. (aproximadamente un millón de U.T.B.) aunque hay pocas industrias que podrían consumir el millón por hora generado. Sin embargo, hay instalaciones de fábrica de calderas convencionales en la Gran Bretaña que generan 500.000 lbas. por hora.

Los cuadros demuestran que para el reactor de agua hirviente del regimen térmico de 40 MW, el aumento de costo capital para economizar una tonelada de carbón por año puede salir a £20,8 para una instalación de calefacción y a £33,5 para una central de fuerza.

Graphite and Molybdenum Disulphide

Factors Affecting their Lubricating Properties in Reactors

by

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(Research and Development Manager, Acheson Colloids Ltd.)

RECENT prominence given to the original work done by Savage on the behaviour of graphite in a vacuum has tended to present a pessimistic view of its lubricating qualities in gas-cooled, graphite-moderated reactors. Whilst MoS_2 offers advantages in certain conditions, its lubricating action is largely dependent upon the changes in surface activity which accompany comminution.

Graphite

In 1928 Bragg[1] showed that the relatively large distances between the layer planes in graphite are a source of weakness in the mutual attraction between these planes and, in turn, give rise to the interplanar mechanical weakness or "slip action" associated with graphite. Later, Jenkins and Holm[2] showed by electron diffraction that graphite crystals are orientated along the main Bragg cleavage planes when their surfaces are rubbed together. Holm followed up this corollary of Bragg's work by suggesting that the occasional wear of graphite surfaces is due to the tilting of the crytals so that their edges are able to abrade adjacent surfaces, and the abrasion could be minimized by the presence of water vapour. It was at this stage that Savage[3] began his work on the behaviour of graphite in controlled atmospheres. This work can be summarized as follows:

(1) The lubricity of graphite is not inherent in the crystal structure alone, but depends on adsorbed films, which provide cohesive forces between the layers of carbon atoms.

(2) "In a vacuum, graphite rods and brushes seize upon a moving base (copper or graphite) and wear away as a fine dust. This wear and accompanying high friction are instantly stopped by some *condensable** vapours at low pressures (H_2O, C_6H_6, NH_3 . . .) which apparently effect the coverage of the graphite by a reversible adsorption governed by the pressure and surface temperature. Under conditions of optimum coverage (zero wear) the graphite friction is still appreciable, but may be accounted for as the heat of cohesion of the water monolayers attached to the carbon atoms and undergoing successive makes and breaks."

Initially, Savage had found that the friction and rate of wear of his graphite rods on copper was low, and recognized that this must be due to the presence of contaminants which encouraged orientation. He, therefore, standardized his experimental conditions by:

(a) Baking out the wear apparatus in vacuum at 400°C.

(b) Firing the graphite in vacuum.

(c) Cleaning the copper disc so that its surfaces were hydrophilic and remained so in a vacuum.

The cleanliness of the copper disc was very important, as a disc which had been polished with fine abrasives and a buffing wheel retained grease which was hydrophobic even in vacuum. Eventually the surface was cleaned electrically in sodium carbonate solution followed by water wash.

It is important here to note that such rigid conditions of purity are never met with even in nuclear engineering practice. Furthermore, "dag"** colloidal graphite is graphite plus an adsorbed layer of stabilizing molecules which in non-aqueous solvents impart a hydrophobic surface to the graphite.

When Savage repeated his paper to the Summer Conference on Mechanical Wear at M.I.T.,† a former associate (W. E. Campbell) had some independent observations to make which confirmed Savage's work as far as it had gone. In addition, however, Campbell had examined both brush and track by electron diffraction and was able to show strong orientation on both brush and track when the rate of wear was negligible. He also reported[4] that when the brush was first "run-in" for a few minutes in moist air, and then dry nitrogen, negligible wear took place indefinitely (Fig. 1).

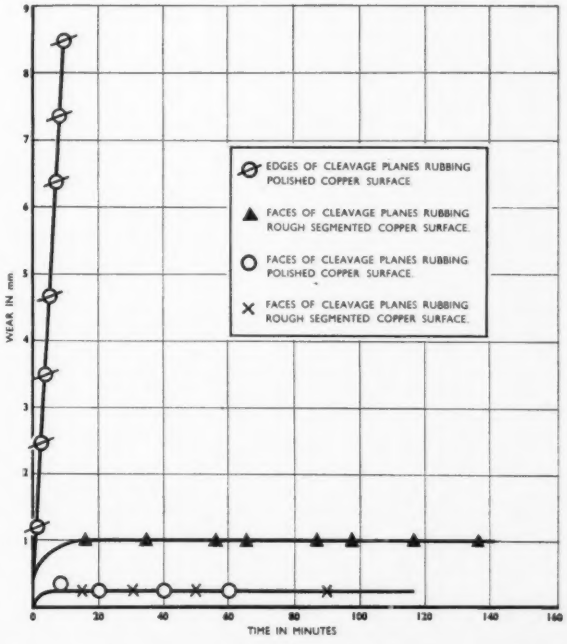

Fig. 1. Wear versus time of orientated carbon preparation in dry nitrogen.

* Carbon dioxide is a condensable vapour.
** Registered trade-mark of Acheson Colloids Ltd.
† June, 1948.

It should, therefore, be noted that when graphite is to be used as a lubricant in atmospheres other than air, the surfaces should first be "run-in" with graphite under normal conditions. It is a fact that graphite will lubricate efficiently in high vacuum (10^{-6}mm Hg) if the temperature does not exceed about 300°C.

Savage replied to this new slant of Campbell's by saying: "Mr. Campbell's modified explanation of graphite lubrication . . . is an ingenious one which should further experiments."

Campbell also made an interesting observation—which has been ignored by writers in this and other journals—on the subject of lubrication of control mechanisms for reactors . . . that the rate of wear of graphite varies inversely as the partial pressure of CO_2 (Fig. 2) . . . although he does not specify a time factor.

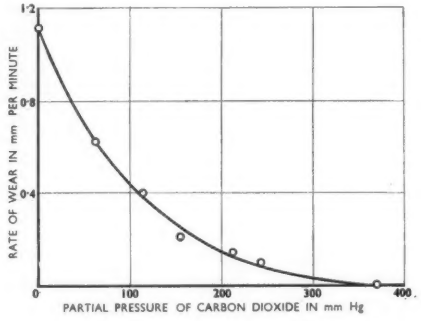

Fig. 2. Rate of wear of carbon brush plotted against partial pressure of carbon dioxide in nitrogen.

It is known that the lubricating action of graphite can be influenced by the surface finish, hardness and speed of the rubbing surfaces and the all-important time factor. One should, therefore, also recognize the contribution of these variables in a given mechanical system, when assessing the efficiency of a solid lubricant for that particular system.

Molybdenum Disulphide

There are several theories on the lubricating action of MoS_2. While all are agreed that the MoS_2 platelets slide over one another (in a manner analogous to graphite), due to the fact that Mo-S bonds are stronger than S-S bonds, the role of contaminants is disputed. There is no doubt that the efficiency of MoS_2 as a lubricant is allied closely to its oxidizing properties and the author's work has largely been concerned with a study of the surface oxide layers on MoS_2 powders.

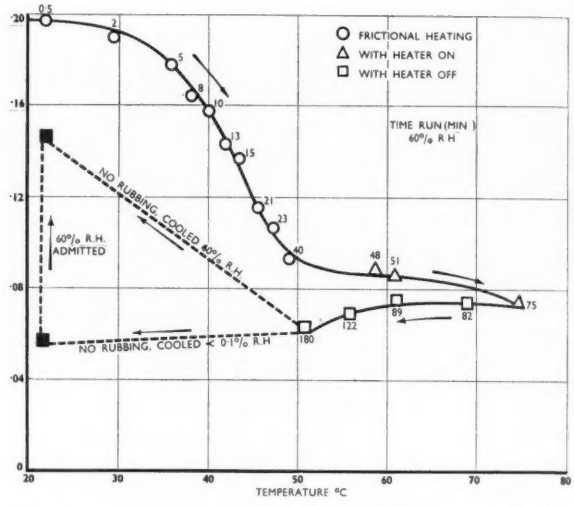

Fig. 3. Temperature for natural molybdenum disulphide lubricated mild steel.

Midgley[5] has also observed a decrease in friction with rubbing time, arising from the drying of the film due to frictional heating (Fig. 3). Whilst Peterson and Johnson[6, 7] had previously shown the effect of humidity on friction characteristics of MoS_2 films, they did not appreciate the significance of *time* of heating.

The Johnson school theorize that MoS_2 lubricates well only when it has an adsorbed monolayer of amorphous sulphur on the crystal surface. On ageing in vacuum, this layer may be removed by evaporation with an attendant increase in the friction value. Additional running releases more sulphur to recreate the monolayer, giving a lower coefficient of friction.

As a result of work carried out by the author[8] on the high vacuum treatment of MoS_2 powders at temperatures up to 1,000°C, he postulated that the previous history of molybdenum disulphide powder makes a contribution to its frictional behaviour. During its initial preparation (either by flotation processes connected with molybdenite, or by precipitation techniques used in the preparation of synthetic MoS_2) the powder is in contact with water. This wetting leaves two types of adsorbed water:

(a) Physically adsorbed—removable in vacuo at 150°C.

(b) Chemically adsorbed—probably in the form of hydroxyl groups.

Under high vacuum conditions or during heating we remove some of this "water" and get a larger percentage

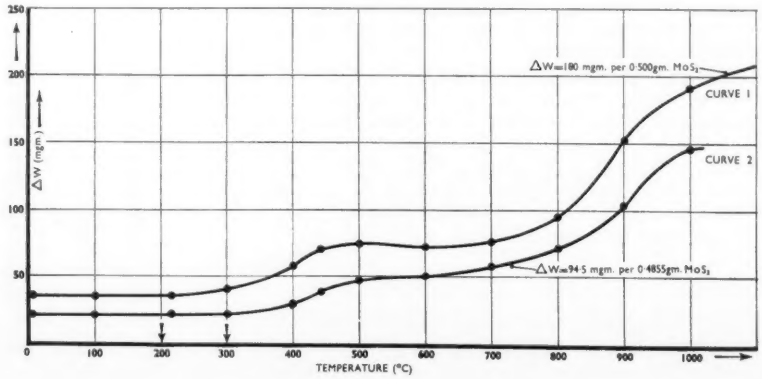

Fig. 4. Thermogravimetric analysis of molybdenum disulphide.

Fig. 5. Photomicrograph (×55) of MoS_2 (S_n=4.05 m^2/g) after heating to 1,000°C.

Fig. 6. Photomicrograph (×55) of MoS_2 (S_n=8.20 m^2/g) after heating to 1,000°C.

of S-S linkages from the Mo-S(OH)S-Mo, which could lead to improved lubricating characteristics.

Following the work of Uyeda,[9] who detected no oxidation of MoS_2 below 440°C, and Godfrey and Nelson,[10] who give a figure of 450°C, the author has studied the oxidation of MoS_2 in pure oxygen using the techniques of thermogravimetric analysis on a Webb auto-recording balance fitted with programme controller and also differential thermal analysis.[8] His results point to much lower figures, and show that the threshold oxidation temperature is dependent on

(a) Surface area.
(b) Nature of surface.
(c) Oxygen concentration.

Thermogravimetric analysis* shows that MoS_2 powder (surface area BET=4.05 m^2/g) begins to oxidize in oxygen at 300°C, whilst a finer powder (surface area BET=8.20 m^2/g) begins to oxidize at about 200°C (Fig. 4). These values were then checked, using the more sensitive differential thermal analysis technique, and values of 305°C and 193°C respectively were obtained. The two experiments were in close agreement.

Photomicrographs of the powders at the end of the experiment show the marked increase in amount of oxidation of the finer powder by the large amount of long MoO_3 crystals which are visible (Figs. 5 and 6). It seemed reasonable from these results that isothermal thermogravimetric analysis at 300°C might be interesting, and the results of such an analysis are given (Fig. 7). In these experiments the apparatus was flushed with nitrogen (washed through pyrogallol) before and during the heat treatment, and it would appear that the residual traces of oxygen in the nitrogen were sufficient to initiate oxidation in the higher surface area powder.

The high heat of reaction ($\triangle H = -266.75$ K cal.) for the oxidation process ($MoS_2 \rightarrow MoO_3$) accounts for an observation by the author that during the oxidation of MoS_2 in pure oxygen, the MoS_2 glows red hot and its temperature may be as much as 500°C in excess of the surrounding temperature.

However, just as we recognize that the experimental conditions of Savage (using pure graphite on clean surfaces) are never met with in practice, so it should be appreciated that the addition of specific resins to "dag" Colloidal MoS_2 can raise the oxidation temperature considerably above the experimental limits given above.

In some applications MoS_2 is most effective as a lubricant when finely dispersed in an oil. It is found, however, that the stability of a dispersion of MoS_2 in oil is affected by the extent of surface oxidation of the particles, and the instability is caused by flocculation of the primary particles. Ballou and Ross[9] showed that, whereas the non-oxidized surface is hydrophobic, oxidized surfaces tend to be hydrophilic. This work of Ballou and Ross is in agreement with later work by the author,[8] who has shown that surface-oxidized MoS_2 which has been washed with ammonia disperses easier in oil than the untreated powder.

Whilst dry MoS_2 coatings might initially be suitable for lubrication in carbon dioxide atmospheres, it is felt by the author that eventually the wear rate might increase due to the gradual break through of the protective layers by carbon dioxide or the oxygen impurity in carbon dioxide. This could scarcely happen with dry graphite coatings, and

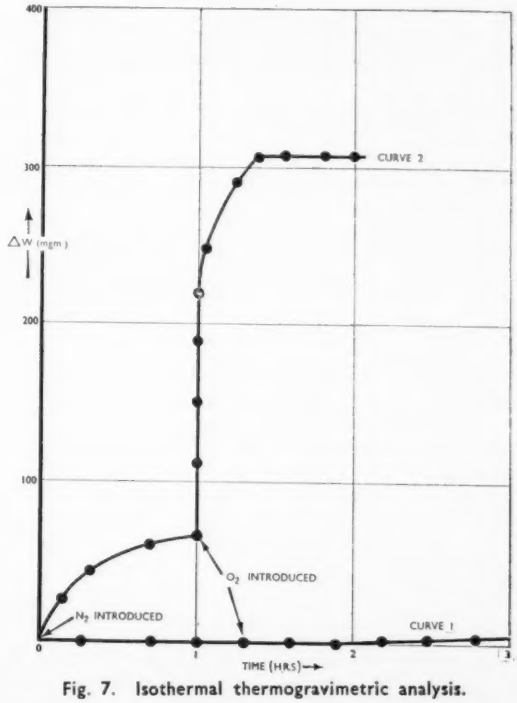

Fig. 7. Isothermal thermogravimetric analysis.

* Unpublished work by author.

investigations along these lines are being pursued by the author using graphite and MoS_2 which have the same resin balance.

Thus far we have considered certain aspects of the lubricating action of graphite and molybdenum disulphide under normal conditions. In a reactor we have an additional variable—the effect of irradiation on the solid lubricant. This effect is most difficult to assess quantitatively in the laboratory, due to the almost impossible task of simulating reactor conditions around a friction or wear-measuring apparatus. However, some work has been done on the changes brought about in the physical properties of graphite by neutron bombardment which enable one to speculate on the possible behaviour of a graphite lubricant in a conventional reactor. As far as the author has been able to ascertain, no comparable work has been reported for molybdenum disulphide.

It is known that graphite undergoes discomposition when exposed to high intensity neutron bombardment and one of the contributory causes is the so-called "Wigner effect". This is the displacement of a carbon atom from its normal lattice position as a result of an energy change brought about by collision with a high energy particle. The effects of such a change are demonstrated by changes in elastic modulus, electrical resistivity, internal coefficient of friction and crystallite volume.

Work at the Materials Testing Reactor at Hanford, U.S.A.,[11] has shown that there is considerable distortion of the crystal lattice in the C_o spacing with a smaller and opposite effect in the a_o spacing at a working intensity of 20×10^{20} neutrons/cm^2 and at 25°C. It was thought that the increase in C_o spacing was due to the displacement of carbon atoms into new lattice positions, thus forcing the carbon planes to expand so that they can accommodate the displaced atoms interstitially. The irradiation effect was found to be temperature dependent, so that the changes in most physical properties at 150°C were reduced by an order of magnitude from those measured at 30°C.

Cottrell[12] has reported that the internal coefficient of friction of graphite is decreased by an order of magnitude after only a few minutes exposure at 10^{14} neutrons/cm^2. More recently Bacon and Warren[13] have studied the changes in C_o spacing which occur when graphite is irradiated at room temperature. These workers have used a smaller dosage than Woods *et al.*[11] and have recorded a correspondingly smaller change in C_o spacing. It can be concluded, therefore, that under conventional reactor conditions, the crystallographic changes in artificial graphite will be small.

One can fairly summarize the position, therefore, by saying that during the lifetime of a conventional reactor, the probability of crystallographic changes in graphite near the reactor core will be very small (*temperature effect*) as will be the changes, in locations remote from the core (*intensity effect*).

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Le Graphite et le Disulfure de Molybdène

Quoique le disulfure de molybdène offre des avantages pour la lubrification dans certaines conditions, son action lubrifiante dépend en grande mesure des changements d'activité de surface qui accompagnent la réduction de la grandeur des particules. Des commentaires récents sur les travaux de Savage ont eu tendance à montrer les capabilités du graphite colloïdal comme lubrifiant dans les applications de réacteurs sous un jour pessimiste.

Alors que la présence de vapeurs condensables à des pressions réduites peut diminuer considérablement l'usure des tiges et balais en graphite sur une base mobile, on a constaté que le graphite lubrifiera de façon efficace dans un vide élevé si la température de dépasse pas approximativement 300°C. Pour y arriver, toutefois (lorsque le graphite doit être employé comme lubrifiant dans des atmosphères autres que l'air) la surface devrait d'abord être passée au graphite dans des conditions normales.

L'efficacité du disulfure de molybdène comme lubrifiant a un rapport très étroit àvec ses propriétés oxydantes et l'auteur cite des passages de ses propres travaux ayant trait à l'étude des couches d'oxyde de surface des poudres de MoS_2. Sous forme finement divisée, le MoS_2 s'oxyde en MoO_3 avec le dégagement de quantités de chaleur considérables.

Graphit und Molybdän Disulfid

Molybdän Disulfid ist unter gewissen Umständen vorteilhaft als Schmiermittel, seine Schmierwirkung ist jedoch in weitem Masse von Veränderungen in der Aktivität der Oberflächen abhängig, die die Verringerung in der Grösse der Partikelchen begleiten. Neuere Ergänzungen zu der Arbeit von Savage haben die Neigung gezeigt, die Möglichkeiten von kolloidalem Graphit als Schmiermittel in der Anwendung auf Reaktoren in pessimistischem Licht zu sehen.

Während das Vorhandensein von kondensierbaren Dämpfen bei niedrigen Drücken die Abnutzung von Graphit Stangen und Bürsten an einer in Bewegung befindlichen Fläche schon erheblich reduzieren kann, hat man ferner gefunden, dass Graphit in hohem Vakuum als Schmiermittel recht wirksam ist, wenn die Temperatur nicht über rund 300°C hinausgeht. Um das zu erzielen (wenn Graphit als Schmiermittel in einer Atmosphäre, die nicht aus Luft besteht, verwendet werden soll), sollte die Fläche erst mit Graphit unter normalen Bedingungen "eingelaufen" werden.

Die Wirksamkeit von Molybdän Disulfid als Schmiermittel ist eng mit seiner Eigenschaft zu oxydieren verknüpft, und der Autor zitiert Beispiele, die er seinen eigenen Arbeiten entnommen hat, die sich mit dem Studium von Oxydschichten auf der Oberfläche von MoS_2 Pulvern befassen. In feiner Verteilung oxydiert MoS_2 zu MoO_3, wobei erhebliche Wärmemengen frei werden.

El Grafito y el Disulfuro de Molíbdeno

Mientras que el disulfuro de molíbdeno ofrece ventajas para lubricación en ciertas condiciones, su acción lubricante depende mayormente de cambios en la actividad de superficie que acompaña la reducción del tamaño de partículo. Los recientes comentarios sobre el trabajo de Savage tienden a mostrar cierto pesimismo sobre las potencialidades del grafito Coloide como un lubricante en sus aplicaciones a sistemas reactores.

Mientras que la presencia de vapores condensables a bajas presiones puede reducir considerablemente el desgaste de las varillas y escobillas de grafito sobre una base móvil, se ha hallado que el grafito lubrificará eficientemente en un alto vacío si las temperaturas no exceden de unos 300°C. Sin embargo, para alcanzar ésto (cuando se va a usar el grafito en otras atmósferas que no sean el aire), primeramente se debe "suavizar" la superficie con grafito en condiciones normales.

La eficacia del disulfuro de molíbdeno como lubricante está asociada estrechamente con suspropriedades oxidantes y el autor cita ejemplos de su propia obra relacionada con el estudio de las capas superficiales de polvos MoS_2. En una forma finamente dividida, MoS_2 se oxida en MoO_3 con la liberación de cantidades considerables de calor.

Thermal and Erosion Protection

Rokide Process of Sprayed-on Coatings is being used in Nuclear Applications

A PROCESS for the protection of metals and other surfaces against extremes of temperature and thermal shock is being carried out by the Norton Grinding Wheel Co. Ltd., Welwyn Garden City, Herts. It was developed in America by the Norton Company as a result of research into materials and processes with reference to rockets where the propulsion gases may have a temperature exceeding that of white-hot steel. For example, a steel rocket venturi with a throat diameter of about 4 in. can increase $\frac{1}{2}$ in. in diameter in 10 sec. firing through a combination of melting and erosion by the high-speed hot gases.

The Rokide process, evolved from this research, is a method of spraying on protective coatings of high melting-point pure oxides, spinels and other materials to metal, graphite and other surfaces. The coating is carried out on the cold base material and even an oxide such as zirconia, with a melting point of about 2,500°C, can be satisfactorily coated on to the lower melting-point metals such as aluminium and magnesium. The temperature reached by the material during coating is unlikely to be detrimental, and coatings have actually been applied to certain synthetic-resin materials without visible charring. The thickness can be controlled quite closely and, if necessary, it can be varied for particular locations on an article: coatings up to 2.5 mm have been successfully applied. In addition to metals, other materials which can be coated satisfactorily are solid carbon in various forms, glass, ceramics and asbestos compositions.

Although it is possible to use a wide variety of coating materials, experience has shown that requirements are likely to be suited by one of three materials which have, therefore, been adopted as standards. These are Rokide A (alumina), Rokide Z (zirconia) and Rokide ZS (zircon), the properties of which are given in Table 1.

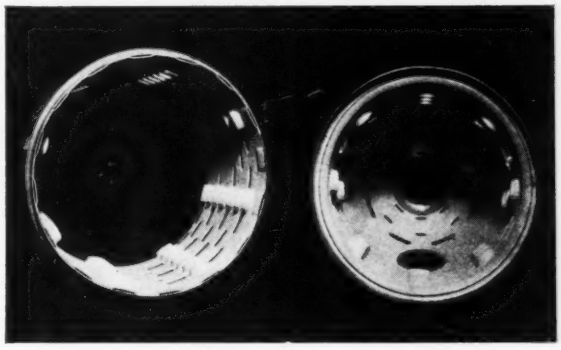
TABLE 1

	Rokide A	Rokide Z	Rokide ZS
Chemical composition ...	98.6% Al_2O_3	98% lime stabilized ZrO_2	65% ZrO_2 34% SiO_2
Crystal form	Gamma-type	Cubic ZrO_2	Cubic ZrO_2 silica glass
Bulk density, g/cc	3.2	5.2	3.8
True density, g/cc	3.6	5.7	4.15
Total porosity	8-12	8-12	8-12
Thermal expansion $\times 10^{-6}$/°F from 70°F-2,550°F	4.3	6.4	2.3
Thermal conductivity, B Th.U./ft. min./°F at 1,500°F mean	19	8	15
Total emissivity	0.3-0.4	0.3-0.4	0.3-0.4
Melting point, °F	3,600	4,500	Glassy phase at about 3,000
Hardness, Knoop	2,000	750	1,000
Colour	White	Tan	Tan

The nature of the process is such that molten droplets of the coating material freeze on to the surface of the metal and on each other to form an interlocking layer structure of low porosity and this layering effect apparently increases the flexibility of a normally rigid brittle material. In addition to this mechanical flexibility, the ability of the coating to adjust to stresses also results in high resistance to thermal shock.

The greatest thermal protection is given by Rokide Z, but if temperatures in excess of 1,200-1,300°C are accompanied by severe erosive conditions Rokide A may be indicated. In certain cases Rokide Z has provided the principal thermal barrier, whilst a thinner superimposed layer of Rokide A assists in taking care of erosion. Where resistance to erosion or wear in any form is the prime requirement, Rokide A is usually the first choice, although Rokide ZS may often be satisfactory, particularly where there is no considerable thermal problem. All coatings are electrically non-conducting, although the resistance of Rokide Z decreases rapidly above 1,200°C. For high-temperature electrical insulation Rokide A is recommended and Rokide ZS may be considered when relatively low temperatures are concerned.

Voltage break-down tests carried out on normal coatings 0.002 in., 0.005 in. and 0.010 in. thick under normal atmospheric conditions gave figures of approximately 500 V, 1,000 V and 1,500 V respectively, but these figures can be increased considerably if the porosity is first sealed by applying a silicone resin varnish to the coating. If operating temperatures should exceed the decomposition temperature of the varnish, the residual decomposition products do not detrimentally affect the electrical properties of the coating.



Jet-engine combustion tube coated with Rokide Z.

So far as nuclear applications are concerned, the coatings have been used on containers for molten salts, such as coated beryllium crucibles and aluminium-oxide-coated graphite crucibles. The process is particularly applicable to the electrical insulation of heaters, erosion protection of graphite and for bearings operating in high temperatures as in heavy-water circuits.

The coating operation is a simple one. The coating materials are in rod form and a special pistol-type oxy-acetylene flame spray-gun is used.

The Norton Grinding Wheel Co. Ltd. are prepared to grant user licences under the patent and supply the spraying equipment and rods. The equipment is being made by Metallisation Ltd., Dudley, Worcestershire, who will also supply units and rods, and licences will be granted to users recommended by them.

The Enrico Fermi Power Reactor

Michigan Fast Breeder Project

The Enrico Fermi reactor project, to be constructed at Monroe, Michigan, has recently been in the news due to an objection raised by certain labour unions regarding its siting. This objection seems largely political in inspiration and appears, according to newspaper reports, to be based on a legal technicality. This description of the reactor is based on a paper read before the American Society of Mechanical Engineers at the A.S.M.E. Annual Meeting, New York, November 25-30, 1956. The authors are John F. Anderson, of the Power Reactor Development Co., W. N. McDaniel, A.M.A.S.M.E., of Atomic Power Development Associates, and C. M. Heidel, of the Detroit Edison Co.

THE Enrico Fermi atomic power plant is a fast breeder design for an initial output of 300 MW (heat) and an ultimate output of 430 MW (heat). The capacity of the generator to be installed is 156 MW, steam being generated via primary and secondary sodium circuits with heat exchangers, the primary sodium circuit and the intermediate heat exchanger being within the containment vessel.

Reactor

The reactor core and blanket consist of a cylindrical assembly some 6 ft. 8 in. in diameter and 5 ft. 10 in. high, containing 91 core elements, 546 radial blanket elements and 10 control rods. The dimensions of the actual core portion are aproximately 31 in. diameter and 31 in. high.

Each of the core elements consists of a double-walled tube, 2.646 in. square section, containing lower blanket, fuel and upper blanket sections. The fuel is in the form of 144 long, thin pins, arranged at 0.1917-in. centres. Each fuel pin is formed of uranium-molybdenum alloy enriched to approximately 25% with U^{235}, this being co-extruded with a zirconium cladding, thus forming a metallurgical bond between the fuel and the cladding. The final dimension of 0.158 in. diameter (including 0.004 in. zirconium) is obtained by cold swaging. The finished length of each pin is $31\frac{3}{16}$ in. and spacing is ensured between pins by stainless-steel wires at 2-in. intervals. The lower ends are anchored, the upper being left free for expansion. As previously mentioned, the square sheath is double-walled, there being a thin sheath around the fuel elements with a thicker wrapper around it, the space being maintained by stainless-steel wire spiral. The coolant flows through the space between the sheaths as well as directly around the fuel pins; by this means, the temperature gradient through the wrapper is reduced.

The upper and lower blanket sections consist of 16 unalloyed uranium pins 0.456 in. in diameter, each clad with a stainless-steel tube 0.484 in. outside diameter and 0.01 in. wall thickness, the space between the uranium and its tube being filled with sodium, and an inert gas space being left in the top of the tube for uranium growth.

The radial blanket elements are generally similar to the blanket portion of the core assemblies, but have 0.415-in. pins with a tube diameter of 0.443, the total length being 72.25 in. with approximately 5 in. space left for inert gas and sodium.

Control Rods

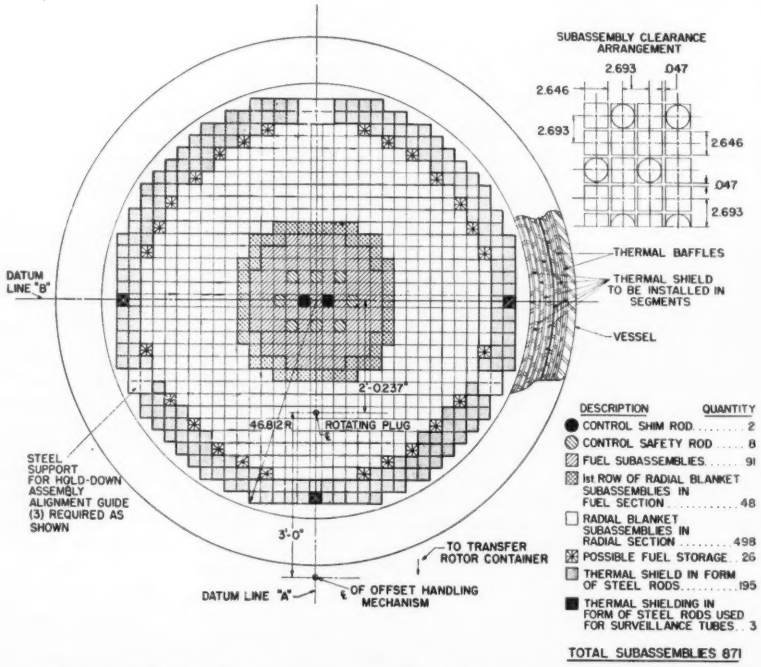
There are eight safety rods and two shim rods, all of boron carbide enriched with boron-10, the operational position being in the upper portion of the axial blanket. Latch releases are provided for scramming, the fall being assisted by accelerating springs and retarded by dashpots at the end of their travel. The boron section is circular and about 31 in. long. Shim rods are about 8 in. in length and move at the relatively low speed of 9 in./min.

Reactor Vessel

The reactor vessel is of 2-in. thick stainless steel, and is generally as shown in the accompanying illustrations. At the bottom of the vessel are two plenum chambers for the inlet of sodium coolant to both core section and radial blanket sections, which are fed at different pressures. Some 90% of the coolant flows through the core assembly with a velocity of 30 ft./sec. and 7% through the radial blanket, at a much lower velocity. The remaining 3% is distributed to the control rods (which are fed through pressure break-down orifices in the bottom of each guide tube) to the thermal shield and an allowance is made for by-pass leakage. The high velocity of coolant in the core region requires that all the elements shall be secured against lifting, and this is effected by a hold-down plate assembly shown in the illustration.

Fuel Changing

The fuel-changing mechanism can be seen from the illustration. The reactor



Key plan of reactor vessel, showing disposition of fuel, blanket and shielding.

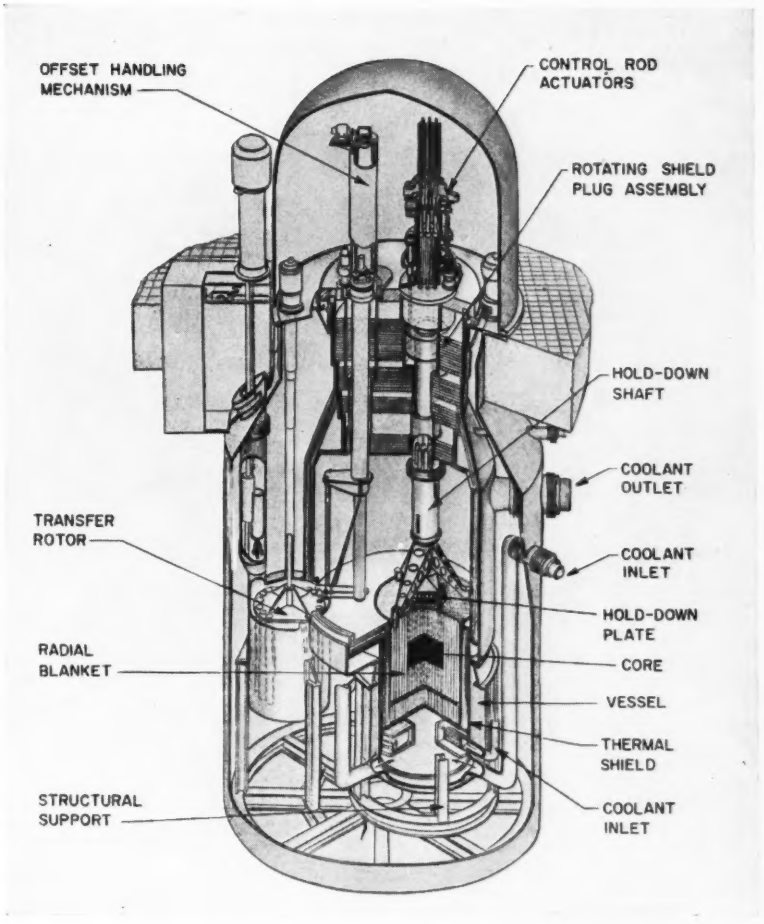
vessel proper is closed at the top end by a heavy rotating shield plug assembly which contains an offset handling mechanism or crane, enabled, by its eccentric mounting, to be located accurately above any particular element. Alongside the vessel is a transfer rotor fitted with compartments for delivering fresh elements to the crane or receiving irradiated elements from the crane. A second handling mechanism is located above the opposite side of the transfer rotor for removing the irradiated elements from the reactor zone.

The gripper devices on both cranes are of the positive-action type, the jaws being positively operated by cams which are moved by specially shaped cam pieces on the top of each fuel and blanket element. The gripper fingers cannot be released while carrying an element, which must be in its proper place at the proper height before release can be effected. All electrical mechanisms are located above the shield plug in a low-temperature, low-radiation zone, and remote maintenance and removal is possible, all parts of the crane being dismountable from above.

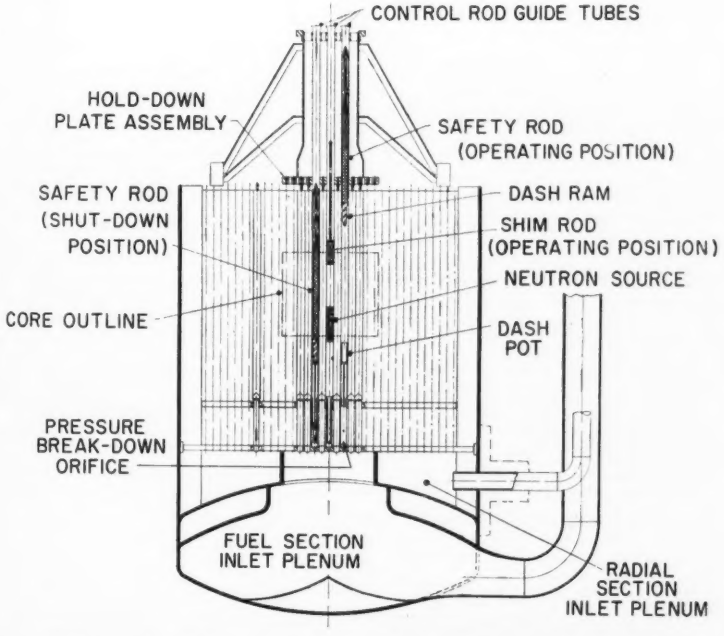
Shielding

Steel rods are used for the "first-line" thermal shielding within the reactor tank, these being approximately similar in dimensions to the blanket units. The next line of thermal shielding consists of a number of concentric steel cylinders installed in segments, also within the vessel, the total of these two being such that the reactor vessel itself never accumulates more than 10^{22} n.v.t. of neutrons above 0.1 MeV.

The reactor vessel itself is, as can be seen from the illustration, surrounded by



Cut-away view of reactor, showing general arrangement and method of fuel charge and discharge.

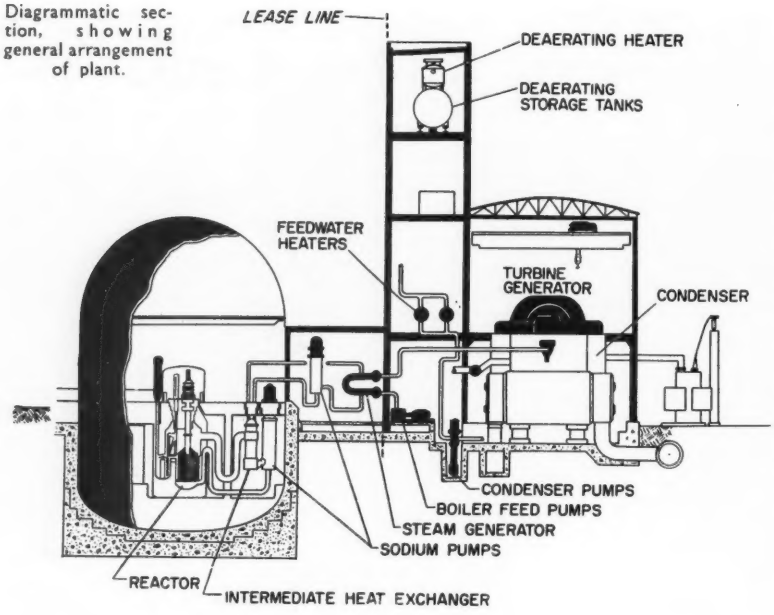


Diagrammatic section of reactor vessel, showing control-rod positions.

a vessel which is referred to as the primary shield tank. Outside this, again, is the secondary containment vessel, borated graphite being installed in the annular space between the two, cooled by inert gas. Outside this is a secondary shielding compartment of concrete and steel, the sodium pipes being surrounded by a 20-in. thickness of dehydrated borax to prevent the escape of neutrons into the machinery compartment.

Outside all is the main reactor containment building, a cylindrical pressure vessel 72 ft. in diameter and 120 ft. high overall with a hemispherical top and an ellipsoidal bottom. The vessel is designed in accordance with the A.S.M.E. Boiler and Pressure Vessel Code, and will be fabricated from 1.03-in. plate and 0.52-in. plate for the top dome, the plate being A.S.T.M. firebox-quality grade B. No field stress-relieving will be carried out. This containment building is surrounded by a biological shield of concrete 7 ft. thick.

This building is designed to take care of the containment of any chemical pro-



Diagrammatic section, showing general arrangement of plant.

ducts of a sodium-air reaction and to withstand shock waves and missiles resulting from an instantaneous energy release.

Heat Transfer

There are three primary and three secondary heat exchangers, both of the shell and tube type. Sodium pumps on both primary and secondary systems are of the centrifugal type, with shaft sealing by inert gas. Check valves are installed in the discharge lines of each pump to prevent flow reversal in case of a pump failure.

The secondary coolant loops are completely independent and no check valves are required. Steam conditions, initially, are 600 p.s.i. and 755°F and the initial amount of steam is 1,015,000 lb./hr. with feed-water at 400°F. After two years of operation it is envisaged that the steam supply will be 1,470,000 lb./hr. at 900 p.s.i. and 820°F (pressures are absolute). Feed temperature at this stage of operation will be 430°F.

The steam cycle is unusual (compared with conventional plant) in that it requires provision for dumping two-thirds of the reactor heat output while maintaining normal feed-water conditions, so that the reactor can be operated before the turbine is installed or when the turbine is shut-down. This will be carried out by the main condenser, and provision has been made to limit the exhaust steam temperature to 200°F. This is accomplished by first passing the steam through the de-aerating water storage, thus desuperheating it to the saturation temperature of 340°F, and then cooling it by condensate from the hot well to 200°F.

In the event of a sudden shut-down involving all auxiliary electrical power, thermal convection is relied upon to get rid of the decay heat from the reactor and the intermediate heat exchanger. The final heat dissipation will be by relieving to atmosphere steam generated from the de-aerator storage, additional condensate being available in an elevated tank.

Site

The plant is to be built on 915 acres of land located three miles south-west of Detroit, at Lagoona Beach, Frenchtown Township, Monroe County, Michigan, and is on the western shore of Lake Erie. It is about seven and a half miles north of Monroe (population 20,000), and within five miles of the site there are four summer resort communities with less than 2,000 permanent residents, which approximately doubles at summer week-ends. The population distribution is approximately 175, 1,800, 31,300 and 187,100 at radii of one, five, ten and twenty miles respectively.

The interested parties are the Power Reactor Development Co., a non-profit-making organization incorporated in Michigan, Atomic Power Development Associates, a non-profit-making company incorporated in New York, and the Detroit Edison Co. A.P.D.A. is the contractor, P.R.D.C. will finance, build, own and operate the nuclear portion and the Detroit Edison Co. will own and operate the plant on the right-hand side of the "Lease Line" in the illustration on this page. Commonwealth Associates Inc., of Jackson, Michigan, are architect-engineers to P.R.D.C. and United Engineers and Constructors, of Philadelphia, are construction engineers to P.R.D.C. and Detroit Edison. The turbine set is by the Allis-Chalmers Mfg. Company.

PERFORMANCE DATA FOR CORE AND BLANKET

	Fuel Section	Axial Blanket Section	Radial Blanket Section
Fuel Unit Dimensions (inches)			
Shape	Square	Square	Square
Outside dimension	2.646	2.646	2.646
Inside dimension	2.454	2.454	2.454
Wall thickness	0.096	0.096	0.096
Space between units	0.047	0.047	0.047
Overall length	98.625	98.625	98.625
Number of units	91	182*	572
Element Dimensions (inches)			
Shape	Round Rod	Round Rod	Round Rod
Clad outside diameter	0.158	0.484	0.443
Clad inside diameter	0.150	0.464	0.423
Uranium diameter	0.150	0.456	0.415
Uranium length	30.5	17	67
Pitch (square)	0.1917	0.587	0.483
Elements per unit	144	16	25
Composition (Volume %)			
Uranium-238	21.35	36.1	46.7
Uranium-235	7.75	—	—
Molybdenum	6.0	—	—
Zirconium	3.8	—	—
Stainless steel	14.9	16.6	19.3
Sodium	46.2	47.3	34.0
Thermal Performance			
Total volume, ft.³	11.65	13	161
Total power, MW	268	4	28
Heat-transfer surface, ft.²	1,378	520	9,250
Average heat flux, B.Th.U./hr. ft.²	665,000	26,000	10,400
Maximum heat flux, B.Th.U./hr. ft.²	950,000	—	570,000
Maximum/average heat flux	1.43	—	55
Coolant flow rate, lb./hr.	11,880,000	11,880,000	925,000
Coolant velocity, ft./sec.	30.3	30	11†
Friction pressure loss, p.s.i.	42	15	5†
Coolant inlet temperature, °F	552	550 (lower)	550
		802 (upper)	
Average coolant outlet temperature, °F	802	552 (lower)	800
		804 (upper)	
Maximum coolant temperature, °F	995‡	867	800†
Maximum clad temperature, °F	1,020‡	910	810†
Maximum uranium temperature, °F	1,300‡	1,120	970†

* There is an upper and lower section in each fuel unit.
† These conditions are for inner blanket unit.
‡ These temperatures include hot channel factors.

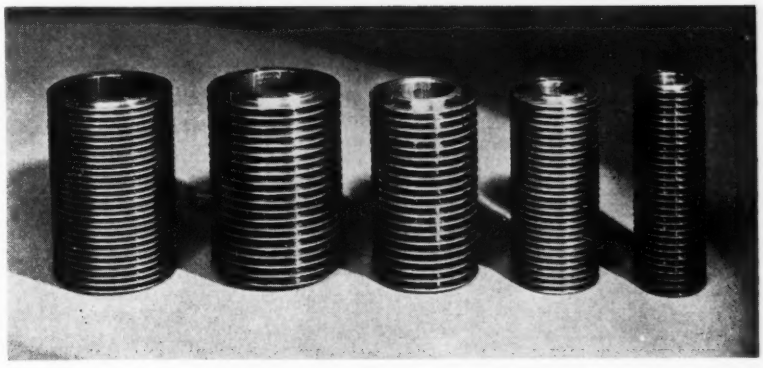
FINNED TUBE

Its place in Nuclear Engineering

A critical factor in the operation of nuclear power stations is the efficiency of heat transfer which can be achieved, both within the reactor itself and subsequently in the steam-raising equipment. Of the types of extended surface tubing developed for both purposes (i.e., for canning the fuel element and in the heat exchangers), one of the most promising has undoubtedly been the transversely-finned tube with integral fins.

This article describes the broad characteristics and the method of manufacture of "Integron", transversely-finned tubing with integral fins.

"Integron" is made under licence in accordance with patents held by the Wolverine Tube Division of Calumet and Hecla Inc., U.S.A. Certain aspects of the production of finned tubing in magnesium alloys and steel have been developed by I.C.I. and are the subject of pending patents.



(Above) Range of High-fin "Integron" tubes.

(Right) Development of High and Low-fin tubes.

Characteristics

The use of extended surface tubing in various types of heat exchanger is well established when there is a considerable difference in the heat-transfer properties of the media inside and outside the tubes. The advantages are, of course, most pronounced for liquid-to-gas combinations. For a particular application, selection of any one of the many types available is based upon the performance offered by the tubing, and the cost. Under the term "performance" must be considered not only the heat-transfer properties of the tubing but such factors as resistance to corrosion, fouling rate, total life, consistency of heat transfer during life, and many others.

When conditions of service are onerous and long life with consistency of operation is essential, tubing in which the fin is a part of the parent metal has many advantages. The risk of fin separation due to vibration, shock or stresses set up by expansion and contraction is eliminated, as also is the possibility of electrolytic action between fins and tubing. The strength of the tube, also, is increased, while heat transfer between fins and tube is at a maximum. Furthermore, the smooth fins offer minimum resistance to the flow of gases or liquids, and minimize accumulation of dust or other obstructions to the flow, thus preventing deterioration of the heat-transfer characteristics.

Types of Integrally Finned Tube

"Integron" tubes have been available in this country for some years in two forms Low-fin and High-fin. They were originally produced in copper and aluminium, but a demand grew for a wider range of materials.

In Low-fin tubing, which is available in sizes from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. nominal bore, there are nineteen fins to the inch and the fin height is such that the ratio of outside surface to inside surface ranges between 3 : 1 and 4 : 1, depending upon the bore of the tube and the material.

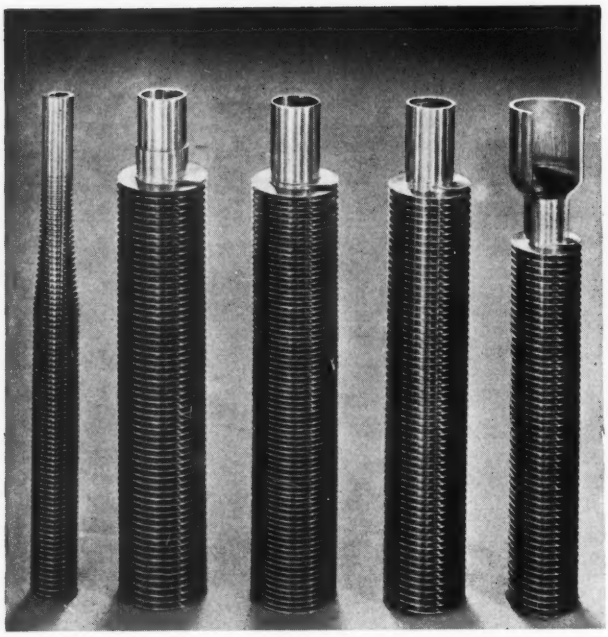
Tubing of this type can be supplied with a number of end finishes, whilst unfinned portions may be left at any required position or positions on the length of the tube. The method of manufacture is such that the outside diameter of the plain tube is greater than that of the finned portion; thus it is possible, without any special precautions, to assemble Low-fin tubes in tube plates and through holes in support plates, the unfinned portions corresponding with the positions of the support plates. Low-fin tube is available in copper, many copper alloys, aluminium, mild steel and certain types of stainless steel.

High-fin tubing is at present produced in sizes between $\frac{5}{16}$ in. and 1 in. nominal bore. The number of fins per inch may be five, seven or nine, and the ratio of outside to inside surface areas ranges from 6.15 in the case of $\frac{5}{16}$-in. bore, five fins per inch tube, to 11.60 for $\frac{5}{8}$-in. bore, nine fins per inch tube, and fin heights are of the order of $\frac{1}{4}$ in. to $\frac{3}{8}$ in.

The method of manufacture of this High-fin tube was for a time such as to restrict the materials to copper and aluminium. The range was widened by the provision of bimetal-finned tubing with liners of other materials but although the heat-transfer characteristics of tubes made in this way are almost equal to those of truly integral tubing of the same size, complications may arise in the construction of the heat exchanger due to the presence of dissimilar materials. This disadvantage has now been overcome by manufacturing developments which enable the High-fin tubes to be made in such materials as copper base alloys, mild steel, etc.

Manufacture

Both High-fin and Low-fin "Integron" tubing are finned helically and are produced by processes similar in many respects to thread rolling. In each instance, three rotating tool assemblies are carried on arbors disposed around the tube at equal intervals. The tools engage with the tube and the first disc-like portion makes a small groove in the stock and



Range of available end finishes for High-fin "Integron" tubes.

the metal displaced is trapped between the first and second disc-like elements. As the tube passes through the tool, the small portion originally trapped is gradually extruded outwards as the space between successive elements is gradually reduced. The process is continuous and the issuing speed of the stock is a function of the rotational speed of the tools and the gear ratio between the circumference of tools and tube.

Theoretically, the method of manufacture enables any material available in tube form, which can withstand the necessary deformation, to be integrally finned. It will be appreciated, however, that with higher-strength materials the power required and tool stresses set certain practical and economic limitations. This is especially so with High-fin tubing, and it has been found that annular, rather than helical, finning is advantageous when dealing with these higher-strength materials. (*Information on the process for producing annular fins is not yet available.*—ED.)

For materials such as brass, cupronickel, steel, etc., the fin dimensions of the tubes produced are comparable with those quoted in the table, the fins, however, being annular instead of helical. Hot finning techniques have been developed for magnesium alloy, as this material is unsuitable for the normal cold-working methods.

Future Developments

The introduction of High-fin tubes in copper alloys, steel and magnesium has taken place within a very short space of time and it is clear that much more development of this process can be expected. In the first instance, the standard products of High-fin tubes in copper, aluminium, copper alloys and steel can probably be improved by increasing the fin height—in fact, on an experimental basis a 25% increase in fin height over that hitherto standardized has already been achieved with aluminium and steel. Other ways of improving the heat-transfer or pressure-drop characteristics of "Integron" tubing are being developed, such as serration of the fins and control of the pitch of the superimposed helix.

The experience gained in hot-finning magnesium alloy has proved valuable in considering possible extensions to the range of materials for integrally-finned tube. Stainless steel, ½% molybdenum steel to B.S. 1652, titanium and beryllium are all under investigation, and in fact any material likely to be used in quantity as integrally-finned tubing will be subjected to finning trials. The designer of heat exchangers can now consider the use of "Integron" integrally-finned tubes in a wide range of corrosion-resistant materials or mild steel.

Application to Nuclear Power Units

(a) Heat Exchanger

The heat exchanger of a gas-cooled nuclear reactor is, of necessity, constructed from extended surface tubing and, in view of the onerous duties and the reliability expected, integrally-finned tubing offers many advantages.

The design of the standard High-fin tube, however, is such that the mean fin thickness is about 0.025 in., and in the light of available knowledge relating to the attack of mild steel by CO_2 at elevated temperatures and pressures, it was considered advisable to increase the fin thickness. By further modification of the tools, mean fin thickness was increased to about 0.064 in., but this was accompanied by a reduction in fin height. Nevertheless, finned tubes in mild steel with nominal bores varying from $\frac{7}{8}$ in. to $1\frac{3}{4}$ in. and fin heights of $\frac{5}{16}$ in. to $\frac{3}{8}$ in. have been successfully manufactured. The ratios of inner to outer surface of these tubes range from 7 : 1 to 8 : 1, depending upon the bore.

Finned tubing of these types is made from steel complying with B.S. 512 and so eminently suitable for boiler tubes, while the finning operation itself is a searching quality test of the tubing.

(b) Fuel Cans

The PIPPA fuel can is another example of an extended surface tube, manufacture of which is possible by fin rolling. For the material used—a magnesium alloy—it has been necessary to develop hot-working techniques and to overcome the problems associated with lubricating both machine and work-piece under these conditions. As a result, it has been possible to produce a fuel can sufficiently close dimensionally to the standard PIPPA can to enable quantity trials to be put in hand. The main objects of this work are to develop the tool design so as to ensure accuracy of fin dimensions, and to permit the development of end finishes which, in turn, will allow existing canning processes to be used with only minor modifications, which should result in a considerable reduction in the cost.

We are indebted to Imperial Chemical Industries Ltd. for the information contained in this article.

HIGH-FIN "INTEGRON"

Nominal size		Fins per inch	Mean fin thickness	Root diameter	Outside diameter of fins	Outside area	Ratio of outside/inside surface areas	Approx. weight
Bore (in.)	Wall thickness (in.)		(in.)	(in.)	(in.)	(sq. ft./ft.)		(lb./ft.)
$\frac{7}{8}$	0.035	5	0.024	0.383	0.869–0.929	0.510	6.15	0.456
$\frac{7}{8}$	0.035	5	0.024	0.445	0.970–1.030	0.613	6.13	0.528
$\frac{7}{8}$	0.048	5	0.024	0.721	1.377–1.471	1.140	7.00	0.950
$\frac{7}{8}$	0.056	5	0.024	0.862	1.518–1.612	1.300	6.65	1.26
1	0.064	5	0.024	1.128	1.784–1.878	1.618	6.19	1.90
$\frac{1}{2}$	0.035	7	0.024	0.320	0.710–0.770	0.476	7.1	0.379
$\frac{7}{8}$	0.035	7	0.024	0.383	0.869–0.929	0.682	8.23	0.460
$\frac{7}{8}$	0.035	7	0.024	0.445	0.970–1.030	0.821	8.21	0.580
$\frac{7}{8}$	0.048	7	0.024	0.721	1.377–1.471	1.52	9.34	1.14
$\frac{7}{8}$	0.056	7	0.024	0.862	1.518–1.612	1.73	8.82	1.44
1	0.064	7	0.024	1.128	1.784–1.878	2.10	8.02	2.10
$\frac{7}{8}$	0.035	9	0.019	0.258	0.545–0.605	0.360	7.05	0.187
$\frac{1}{2}$	0.035	9	0.019	0.320	0.710–0.770	0.576	8.60	0.369
$\frac{7}{8}$	0.035	9	0.019	0.383	0.869–0.929	0.832	10.00	0.533
$\frac{7}{8}$	0.035	9	0.019	0.445	0.970–1.030	1.000	10.00	0.622
$\frac{7}{8}$	0.048	9	0.024	0.721	1.377–1.471	1.900	11.60	1.235

Technical Papers and Publications

A.S.M.E.-A.S.L.E. CONFERENCE

Report of the Joint Lubrication Conference of the American Society of Mechanical Engineers and the American Society of Lubrication Engineers, held in Atlantic City, N.J., on October 8, 1956.

Application Problems with Petroleum Lubricants in Nuclear Power Plants *by R. F. Hausman and E. R. Booser (Atomic Power Equipment Department, G.E.C.).* **General Radiation Damage Problems for Lubricant and Bearing-type Materials** *by V. P. Calkins and C. G. Collins (Aircraft Nuclear Propulsion Department, G.E.C.).* **Use of Rolling Contact Bearings in Low-viscosity Liquid-metal Lubricants** *by W. Markert, Jr., and K. Mildred Ferguson (Babcock and Wilcox Co. Alliance).* **Radiation-resistant Greases** *by J. G. Carroll, R. O. Bolt and B. W. Hotten (California Research Corporation).* **Effects of Nuclear Radiation on Lubricants** *by J. A. King and W. L. R. Rice (Wright Air Development Centre, Wright Patterson Air Force Base, Ohio).*

Radiation damage to organic lubricants in a nuclear power plant is due primarily to ionization as a secondary factor of bombardment by fast neutrons, slow or thermal neutrons and gamma rays. Fast neutrons cause damage by interacting with the hydrogen nuclei in the organic materials and ejecting the hydrogen atoms as fast recoil protons. These protons then cause radiation damage by upsetting the electronic system of molecules and producing ionization. Photons of gamma radiation collide with single electrons of the atoms of organic materials, transferring a portion of their energy with each encounter. These electrons are ejected and again there is an upset of the electronic system of molecules with ionization. Deprived of an electron, the molecule becomes an unstable ion and can undergo a variety of chemical changes including polymerization and oxidation. Damage to organic materials by thermal neutrons results primarily from the capture of these neutrons by the nuclei of hydrogen atoms with the subsequent emission of high-energy gamma rays.

Whilst neutron and gamma radiation degrades all organic materials, oils appear to have a certain period during which there is only a relatively minor change in their physical properties followed at some threshold point by a relatively short period over which the oils suffer substantial damage. This is characterized by an increase in viscosity and when this viscosity is increased by 25% of its original value an oil may be said to have crossed the threshold into the severe damage region. There is strong evidence to support the view that the damage is virtually independent of the type of radiation and is a function only of the total energy absorbed. The dosage can therefore be conveniently expressed in rads; in general, the permissible level of irradiation of conventional lubricating oils is from 1 to 2 × 10^8 rads. Beyond this exposure level lubricants and hydraulic fluids exhibit appreciable viscosity change and other degradation effects which interfere with their satisfactory operation. The rapid increase in the viscosity of turbine oils when they are exposed to irradiation which is above 2 × 10^8 rads is indicated in Fig. 1.

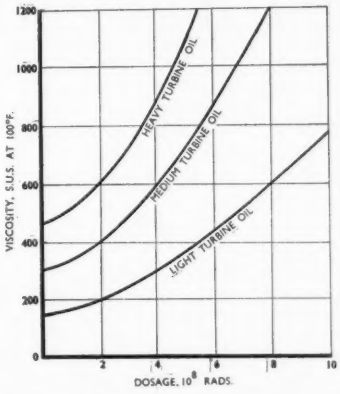


Fig. 1. Effect of radiation on turbine oil viscosity.

Operation can be carried to somewhat higher dosages with organic fluids containing large portions of aromatics. Alkyl benzene fluids have been used to produce oils with improved radiation resistance, as with these and similar aromatic structures the absorbed energy apparently goes to a large extent into resonant energy in the aromatic ring structure. This reduces the damaging ionization and free radical formation which occurs on a much more general basis with chain-like structures in paraffinic oils or in the saturated ring structure of naphthenic oils. Synthetic oils vary somewhat in their resistance to radiation. Although the alkyl benzenes have better radiation stability, they do not provide as good lubrication in reactor tests as do the aircraft-type diester oils or the polyglycol lubricants. Of these three types of oil, Bolt and Carroll concluded that the polyglycol type was the most satisfactory for use in nuclear reactors from a radiation-damage standpoint.

Lubrication in a Nuclear Power Plant

The number of components requiring lubrication in radiation zones will depend upon the type of reactor. With the Calder Hall type, for example, apart from the control-rod mechanisms which are in general located outside the biological shield and the blower systems which are handling only mildly active carbon dioxide, only fuel handling or manipulation gear is of any importance. In any case, more critical features concern the vapour pressure and the working temperature and the necessity for avoiding contamination of the coolant.

Radiation damage is of greater importance in water-moderated reactors such as DIDO (*Nuclear Engineering*, January, 1957) and the pressurized-water reactors, particularly those using "live" steam. Control mechanisms within the reactor shield and some of the remote fuel-handling devices will be exposed to very large radiation doses. The use of any petroleum-based lubricant is likely to be impossible in these cases and resort must be made to judicious bearing materials and the selection of designs which permit lubrication by the coolant water. In heavy-water reactors, of course, a further objection to the use of petroleum-based lubricants would be the contamination of the moderator. The most critical unit, however, in a normal power station is the turbine and generator. Although special design features will be incorporated in turbines for nuclear power plant service, the speeds, bearing loads, and bearing materials will be identical to those in conventional power plants. The lubricating oils will also be identical and paraffinic-type oils of approximately 150 s.u.s. viscosity at 100°F will be used as before.

Pumps can also present special problems, but, in general, the radiation level at the bearings will be sufficiently low for paraffinic oils to be applicable if these are compatible with other features of design. In general, in live circuits, however, submersible-type pumps will be employed which will incorporate bearings suitable for lubrication by the circuit water. Table 1 indicates the radiation levels at selected points in a 12.5-MW single-cycle boiling-water reactor designed to use "live" steam.

A minor complication can be introduced by the metallic additives in paraffinic oils if the oil is exposed to neutron bombardment, due to activation of the additives. In general, however, the increased radiation damage is negligible and disposal of the active oils presents no problem.

Greases

As with oils, there is evidence to indicate that radiation damage is a function of the total energy absorbed irrespective of the type of radiation. Previous work

TABLE 1—RADIATION EFFECTS ON LUBRICANT LIFE IN A TYPICAL NUCLEAR POWER PLANT

Components	Operating Dosage Level, Rads/hr.	Lubricant Life, Hours to attain 10^8 Rads Exposure
Turbine	0.2	10^9
Water circulating pumps	10^2	10^6
Remote fuel-handling devices	10^5	10^3
Control drive mechanisms	10^5	10^3
At reactor vessel wall	10^6	10^2
At reactor core centre	10^{13}	10^{-5}

TABLE 2—EFFECT OF GAMMA RADIATION ON THE CONSISTENCY OF GREASES

Grease type	MIL-L-3545	MIL-G-3278	Silicone	Experimental	G-2
Oil Type	Mineral oil	Diester	Silicone	Alkylbenzene*	Alkylbenzene*
Gelling agent	Sodium soap	Lithium soap	Lithium soap	Terephthalamate	Estersil†
		ASTM Worked Penetration			
Gamma Dosage, $r \times 10^8$					
0	331	277	269	289	296
4	213	Semi-liquid	289	289	—
9	Semi-liquid	Semi-liquid	Too hard	308	—
26	Too hard	Too hard	Too hard	400	—
30	Too hard	Too hard	Too hard	359	—
50	Too hard	Too hard	Too hard	—	388

* With oxidation inhibitor.
† Du Pont Estersil.

has shown that aromatic fluids are more resistant that aliphatic fluids to radiation, and experiments have been made on conventional greases and also on test samples of experimental greases made from alkylbenzene oil (molecular weight 250) inhibited with didodecyl selenide and thickened with a siliceous agent, Du Pont Estersil. Work penetrations were determined on a series of greases to establish a pattern of consistency change as a function of gamma dosage. Table 2 shows results for three commercial greases and two experimental products. It will be noted that the general damage pattern is the same in all cases, showing a period of excessive softening prior to hardening. The limits of the penetrable or semi-liquid state vary with the particular combination of oil and gelling agent and are in one sense a measure of radiation resistance. Grease G-2 was still soft and grease-like for the extreme dosage of 50×10^8 rad. It should be noted, however, that initial bearing life using such greases is not necessarily comparable with those using conventional greases, although the rate of change of bearing life with dosage is very much lower, the bearing life with conventional greases decreasing by a factor of 20 with an irradiation of 6×10^8 rads and the experimental greases by less than 2.

At the same time, oxidation stability following this level of irradiation is significantly impaired and low temperature torque to a minor degree. Copper corrosivity and evaporation, and wear properties as measured by the Navy Gear Wear Tester, were not greatly increased by irradiation.

B.N.E.C.

The Behaviour of Radio-isotopes in Sewage Treatment and the Disposal of Radioactive Wastes to Sewers *by Arthur William Kenny, M.A., B.Sc., (Radiochemical inspector, Engineering Department, Ministry of Housing and Local Government). Institution of Civil Engineers, March* 5, 1957.

The paper does not attempt to discuss the disposal of sewage from the premises of the Atomic Energy Authority, and although the Radiochemical Centre at Amersham does discharge into sewers this is an exceptional case. The discharges under discussion contain one or more of 20-30 radio-isotopes, which in the past ten years have been shown to be important for therapeutic treatment in hospitals. The behaviour of these radio-isotopes can in certain instances be assumed to be comparable, but a complete generalization is not possible. Whilst the level of 0.3 rad per week is taken to be the maximum permissible figure for occupational workers, it is thought undesirable to allow the general public to be radiated to this level and a tenth of this figure is therefore taken. The basic problem with radioactive discharge to sewers is to set limits for the concentration of each of the radio-isotopes present, so that the total amount of radio-isotopes at any point where the public has access is insufficient to irradiate any one with more than 0.03 rad per week on the average. In addition to a knowledge of the radioactive properties of radio-isotopes, the physical and chemical behaviour under the requisite conditions must be known, i.e., how much is absorbed on to sewer slimes, how much is absorbed on the river bottom, etc.

The most important single class of user is the hospital. Its usage may take the form of small doses for diagnostic purposes only or for therapeutic purposes where considerable doses of the order of 100 milicuries can be involved. These large doses are normally of radio-iodine or radio-gold, but radio-phosphorus, sodium and bromine have found important applications. Chromium and yttrium are also being used in increasing amounts and sulphur, iron, carbon, potassium and strontium have found limited use.

The hazard, therefore, can be broken down into occasional discharges of 70 millicuries or more of radio-iodine, occasional discharges of 10-30 millicuries of radio-bromine and radio-sodium and a more or less continuous discharge (1-2 millicuries per day) of the same isotopes from patients receiving treatment together with other isotopes, principally phosphorus, sodium and sulphur.

Experiments have been carried out on the probable contamination of drains in these circumstances. It would appear that if effluent and surface were sufficiently long in contact an equilibrium condition would be set up in which the ratio of active to inactive isotopes on the surface would be the same as the ratio in solution. The rate of flow is probably too fast to allow equilibrium to be set up, but the next discharge of radioactive effluent takes the process a stage nearer equilibrium. Between successive discharges decay of the radio-isotope on the surface occurs and ultimately a stage is reached in which the rate of addition of radio-isotopes on the surface is balanced by rate of decay. The evidence shows that the equilibrium level is not hazardous.

Sewage workers must, of course, be protected, and in this connection a level of 0.1 μc/cc can be considered safe even for accidental emersion with some ingestion by swallowing. Discharge of 70 millicuries will therefore become quickly diluted (total volume required, 150 gallons) down to this level. Effluent from establishments other than hospitals is normally of a lower concentration and most uses involve discharges of considerably less than 1 millicurie per week.

A survey has shown that the levels of activity encountered are considerably below those levels at which damage to the sewage-purifying organism might be expected. The behaviour of radio-isotopes during the sewage purification process is dependent upon the concentration of inactive isotopes and the results so far obtained have shown wide divergences. It can, however, be stated confidently that the amount taken up on filters or activated sludge is not sufficient to be hazardous to workers. Only if relatively large amounts of a long-lived isotope like cobalt-60 were discharged to the sewers would hazardous levels build up.

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One point that needs examination, however, in the discharge of sewage effluent to rivers is the concentration of radioactive isotopes in organic materials such as mud, algæ, fish and so on. Some concentration is known to take place, but it is important to note that just below the outlet from Harwell into the Thames no radioactivity can be detected on the mud of the river-bed. This is not because adsorption does not occur on the mud, but because the adsorbed material is spread over so large a surface and no hazardous level can build up. The disposal of radioactive sewage sludge for fertilizers would appear to present no hazard. Very considerable dilution takes place, quite apart from the long period of time between the initial discharge of the effluent and the final assimilation into a plant which is then used for food.

In general terms, however, it is undesirable that the public be irradiated to a level greater than the absolute minimum because of the overall genetic effect, so that the possibility of contamination of Britain's present and future water supply and the consequent irradiation of considerable populations is a matter for concern. It is, however, worth noting that the irradiation of the public by contamination from radioactive waste disposal did not figure as a significant contributor to the nation's genetic damage in the Medical Research Council's recent survey into the problem.

INSTITUTION OF MECHANICAL ENGINEERS

Some Engineering Problems in Connection with the Industrial Application of Nuclear Energy *by Sir Claude D. Gibb, K.B.E., D.Sc., M.E., F.R.S. (Past Vice-President) (chairman and managing director, C. A. Parsons and Co. Ltd.). 43rd Thomas Hawksley Lecture, Institution of Mechanical Engineers, February* 15, 1957.

After emphasizing the growing power demands in the United Kingdom, coupled with the shortage of coal and the danger of relying on American oil, the paper goes on to deal with the specific engineering problems encountered in the construction of a nuclear power station.

The nuclear physicist will state the minimum size and the amount of uranium to obtain criticality. The thermodynamist and the metallurgist working in the closest co-operation will determine the maximum fuel rating in the centre channel and the maximum temperature permissible in the fuel rod and can. The heat exchanger or boiler designers must then decide how much steam and at what pressures and temperatures it can be supplied to the turbine, whose designers provide the figure for the electrical output. The designers of the duct-work and gas circulators then determine the pressure drop in reactor ducts and boilers and with a known mass flow can design their portions of the plant. In the meantime shield designers will have been calculating the amount of protective concrete and other materials necessary and their figures will influence the civil engineering and duct-work layouts.

The work of the reactor pressure vessel designer is vital to the whole project. He has the option of choosing the cylindrical or spherical vessel, but he must consult the designers of the fuel element charge and discharge gear, and must know the dimensions of how many ducts carrying the gas have to be brought into the reactor shell. He must consider how to transmit the very considerable weight of graphite and uranium through the vessel to the foundations and he must also consider the changes in temperature between inlet and outlet gases and the stress pattern induced in consequence. Finally, there is the crowning problem of the irradiation effects upon the shell materials available to him.

Changing fuel elements in a gas-cooled reactor is relatively difficult and calls for ingenious, costly and massive charge and discharge machines, but the problems to be solved in changing fuel elements with liquid-metal cooling while the reactor is on load are much greater and when allied to the determining of faulty fuel elements will call for exceptional ingenuity.

The designer of industrial nuclear stations must never lose sight of his prime object, which is to produce electricity at the lowest cost consistent with safety and reliability. There are so many solutions to nuclear power problems that appear to offer advantages in one or other direction but always either at the expense of safety or generating cost, so that they provide pitfalls to generating costs.

Principles and Applications of Spark Machining *by D. W. Rudorff (director, Sparcatron Ltd., Research Department, London). Institution of Mechanical Engineers, London, February* 22, 1957.

The historical background of electro-erosion technique is briefly outlined and the difference between spark and arc discharges is defined. The underlying principle of the relaxation-type spark circuit as employed in industrial machines is explained, and development trends are discussed. The various factors bearing upon the efficiency of spark-erosion operations are enumerated. The mechanical features of a typical spark-erosion machine are described, and the range of machining operations for which spark-cutting machines can be designed is outlined. Typical samples of work produced on a commercial unit are described and illustrated, and the properties of spark-machined surfaces are discussed.

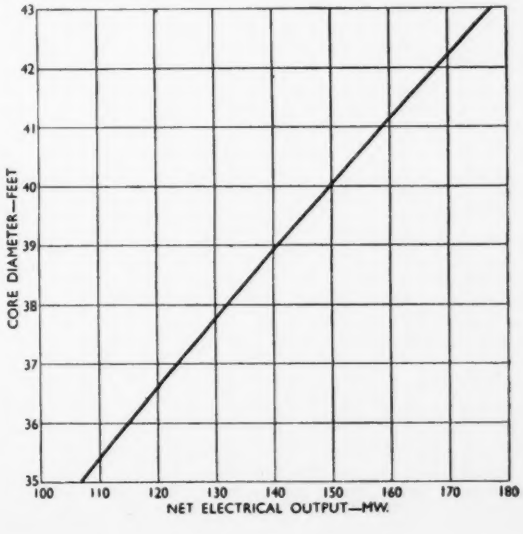
INSTITUTIONS OF CIVIL, MECHANICAL AND ELECTRICAL ENGINEERS

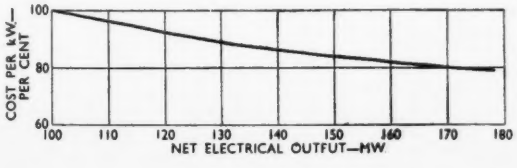
The Place of Engineering in University Education *by Sir Ifor Evans, D.Lit. (Provost of University College, London). Third Graham Clark Lecture, held at Institution of Electrical Engineers, February* 7, 1957.

The lecturer considers the present situation of engineering in our universities and its prospects for the future. He affirms that the universities should be concerned mainly with fundamental disciplines. Too often in the past there has been the misunderstanding that engineering is solely the study of technical expertness and of professional

(Right) Core diameter and net electrical output (Sir Claude D. Gibb).

(Below) Capital cost and net electrical output (Sir Claude D. Gibb).





practice. This is certainly not true today and probably never was.

Engineering is a discipline as good as any other and better than some. Engineering as it is studied in the universities has taken over a substantial part of classical physics, makes heavy demands on mathematics and in its manifestation employs these and other studies to its own purpose. It is possible that necessary development of engineering departments in the universities may have come too late and this must be acknowledged as being due in part to an active social and pedantic antagonism to university engineering studies. This can be exemplified in tracing the history of engineering faculties in the universities of Oxford, Cambridge and London. Oxford particularly has been very slow to accept engineering as a sound academic subject.

There is clearly a national concern over this situation, but a balanced approach is required. We need today not a competitive attitude, but a knowledge that science and the study of man in his environment and all the arts contribute to a common whole which we call civilization. Apart, however, from increasing the number of engineers, it is necessary to make the increase effective and a new view is necessary of national life. It is not necessary to make comparisons with the United States and Soviet Russia—an examination of our unique situation suffices. In all the discussions of these problems in recent years, the 1956 Report on Scientific and Engineering Manpower in Great Britain is the most realistic. The conclusion drawn is that the number of people required each year in science and engineering would need to increase from 10,000 in 1954-55 to about 20,000 in 1970, an increase of about 100%. This is not impossible, as at University College London, for example, engineers represent not more than 8% of the student population. On the other hand, figures issued recently show that some of the provincial universities, after accepting all qualifying engineers, have vacancies; and in a large college of technology, although there has been a large increase in intake of engineering students for 1956-57, this is due entirely to the inclusion of a large batch of overseas students.

All this reflects on not only the number but the quality of the students entering into the engineering field, and it is necessary that more young students should be encouraged to consider engineering as their main theme. This is a public relations task of a major character and the lecturer suggests that industry could combine with the Institutions and possibly some of the leading public relations specialists to undertake this great task.

Again, there must be a change of mind in the higher direction of firms as to the part that engineers can play in management. If the country is to have a new industrial policy which is essential for our existence there will be increasing opportunities for the scientist and engineer to go right through—if he has the right qualities—to the very top. In the smaller firms there is a great deal of room for further encouragement for the scientist to occupy more important positions than now seem to be open to them.

The real weakness of our university engineering training as a whole lies in the weakness of the post-graduate courses. In the universities one or two very fine courses are offered, but they are still pathetically few. For example, nuclear development in industrial application to power is to be a task more for the engineer than the physicist.

Seen in perspective, our problem is an understanding of scientific methods in the whole of our education from school age onwards, and not regarded as an odd, temporary emergency call for engineers as if one were calling for the fire-brigade.

INSTITUTE OF FUEL

The Rise of a Hot Waste Gas Plume *by C. H. Bosanquet, M.A. (Research Department, I.C.I. Ltd., Billingham division). Meeting at Institution of Civil Engineers, February* 13, 1957.

It is assumed that when a cloud of hot gas is rising the total heat content and total upward momentum are unaffected by dilution with atmospheric air. It is also assumed that the upward momentum increases at a rate proportional to the heat content. Rate of dilution is assumed to be proportional to the surface area of the cloud multiplied by a function of the wind velocity and the velocity of the cloud relative to the surrounding atmosphere. From these principles an equation is developed for finding the track of hot waste gas rising from a chimney in a wind of any velocity. The height to which the waste gas rises depends on both its heat content and its exit momentum and tables are given for calculating the combined effect. It is shown that if the temperature gradient in the atmosphere is less than adiabatic, the smoke will not continue to rise indefinitely but will eventually settle down at a definite height.

Maximum Gas Concentration at Ground Level from Industrial Chimneys *by A. C. Best, O.B.E., D.Sc. (Meteorological Office, Air Ministry). Meeting at Institution of Civil Engineers, February* 13, 1957.

The ground-level concentration of gas emitted from a chimney reaches a greatest value at a particular distance downwind from the chimney. Both the distance and the concentration itself depend upon the design characteristics of the chimney and upon the meteorological conditions. If the height to which the plume of gas rises above the chimney, owing to heating or velocity of efflux, is known, the maximum concentration likely to occur in any weather conditions can be calculated. It is this maximum concentration which is of interest when the stack is being designed. Several formulæ for computing the height of rise have been published. The results of using three of these formulæ have been considered, and it is shown that for the purpose of computing maximum ground-level concentration the three are in reasonable agreement.

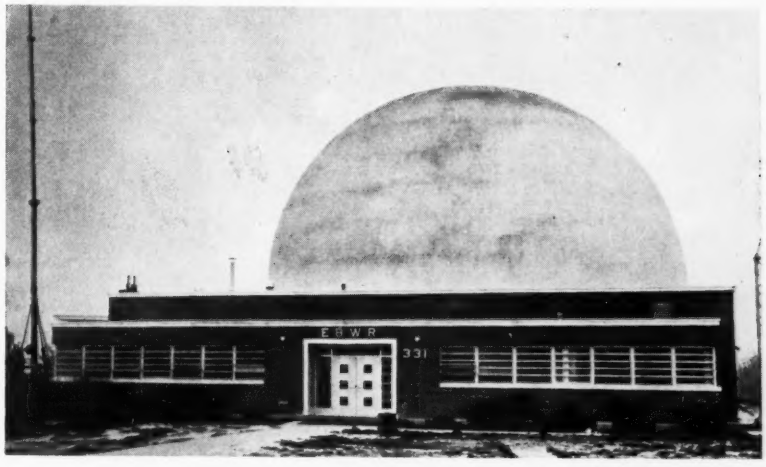
FORTHCOMING EXHIBITIONS

PHILADELPHIA:	International Atomic Exposition and Nuclear Congress. March 11-15.
COPENHAGEN:	11th International Fair (Technical Section). March 19-27.
LONDON:	Physical Society Exhibition of Scientific Instruments and Apparatus. March 25-28. Old and New Horticultural Halls.
LONDON:	3rd International Instrument Show. March 25-29. Caxton Hall.
LOS ANGELES:	Western Metal Congress and Exhibition. March 25-29.
LONDON:	14th Radio and Electronic Component Show. April 9-11. Grosvenor House, Park Lane.
LONDON:	6th Electrical Engineers' Exhibition. April 9-13. Earls Court.
LYONS:	39th International Trade Fair April 27-May 6.
BRUSSELS:	31st International Trade Fair. April 27-May 12.
LONDON:	5th Factory Equipment Exhibition. April 29-May 4. Earls Court.
BIRMINGHAM:	British Industries Fair. May 6-17.
LONDON:	Instruments, Electronics and Automation Exhibition. May 7-17. Olympia.
LONDON:	Protective Clothing and Safety Equipment Exhibition. May 13-17. Olympia.
PARIS:	47th International Trade Fair. May 25-June 10.
BIRMINGHAM:	Safety and Factory Efficiency Exhibition. June 14-21. Bingley Hall.
AMSTERDAM:	International Atomic Exhibition July. Schipol Airport.
MUNICH:	Applied Atomics Exhibition and Trade Show. July 5-21.
LONDON:	4th British Plastics Exhibition and Convention. July 10-20. Olympia.
LONDON:	21st Engineering Marine and Welding and Nuclear Energy Exhibition. August 29-September 12. Olympia.
NEW YORK:	Atomic Show. October 28-31. Coliseum.
CHICAGO:	2nd World Metallurgical Congress and 39th National Metal Congress and Exposition. November 2-8.
LONDON:	27th Building Exhibition. November 13-27. Olympia.
NEW YORK:	26th Chemical Industries Exposition. December 2-6.

Experimental Boiling Water Reactor

First U.S. Power Plant Officially Opened

THE Experimental Boiling Water Reactor at the A.E.C.'s Argonne National Laboratory (Lemont, Illinois) was officially dedicated at 2.30 p.m. on Saturday, February 9, criticality having been achieved on December 1 at 7.20 a.m. It is of particular interest as being the first nuclear power plant to operate in the U.S. and the first practical use of directly-generated steam without an intermediate heat exchanger. With its output of 5 MW electricity and 20 MW heat, it is intended not as a commercial plant but as a large-scale experimental unit that will enable answers to be obtained to a great many questions not only concerned with the reactor itself, but with such items as the activity accumulated by the steam plant and the extent and effects of corrosion and leakage.



Outside view of the EBWR.

Reactor

As in the case of the rest of the plant, flexibility is the keynote of the reactor design, which, for example, provides for a change in core diameter from 4 ft. to 5 ft. and fuel elements of different dimensions to allow the water : uranium ratio to be adjusted and the determination of the influence of steam voids on the stability. Fuel elements of different enrichments are available to permit variation of the critical size and power distribution pattern.

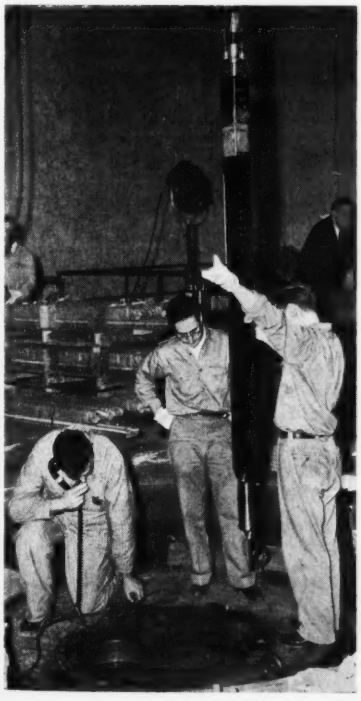
The core at present consists of 114 fuel elements, of which 106 contain enriched fuel (1.44% U 235). There is capacity for 148 fuel elements when working with a 5-ft. diameter core; at present the extra spaces are filled with dummy elements.

Each of the fuel elements is 77⅛ in. long and 3¾ in. square and consists of six fuel plates and the top and bottom end fittings. The fuel plates themselves are uranium-zirconium-niobium alloy, clad with Zircaloy-2, the side plates being also of Zircaloy-2; end fittings are of stainless steel. The dummy elements are made of aluminium-nickel alloy, which has given promising results in preliminary corrosion tests.

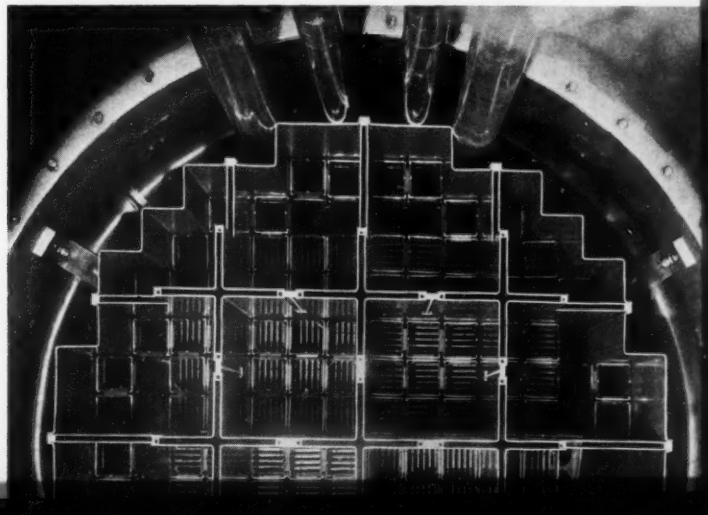
The control system is of unusual design in that, although the rods are lifted out of the core to reduce neutron absorption, the raising is done from beneath the reactor. The control rods are of cruciform section operating in cruciform-shaped channels left in the core support and shroud structure. There are nine control rods, five being made of hafnium and four of stainless steel containing 2% boron. Each of them has a zirconium follower section of the same shape, which fills the channel when the absorber section is raised out of the core. Scram insertion of the rods is effected by a combination of gravity, steam pressure and springs, external dashpots being used for deceleration.

Vessel

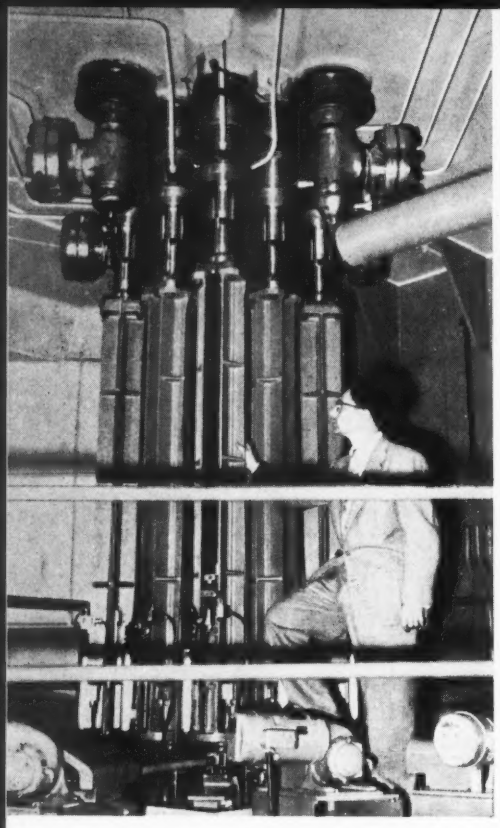
The main pressure vessel is 31 ft. high and 7 ft. internal diameter. It was fabricated by the Babcock and Wilcox Co. from aluminium-killed steel (S.A. 212 Grade B Firebox Quality) 2¼ in. thick with 0.109 in. stainless-steel cladding. Fabricated to 1952 A.S.M.E. Power Boiler Code, it was subjected to hydraulic tests and helium leak tests at 1,200 p.s.i., in addition to the normal radiographic tests. The top flange of the vessel is a forging. The top closure consists of a bolted cover plate, with a double gasket seal, and a shielding plug with removable inserts located im-

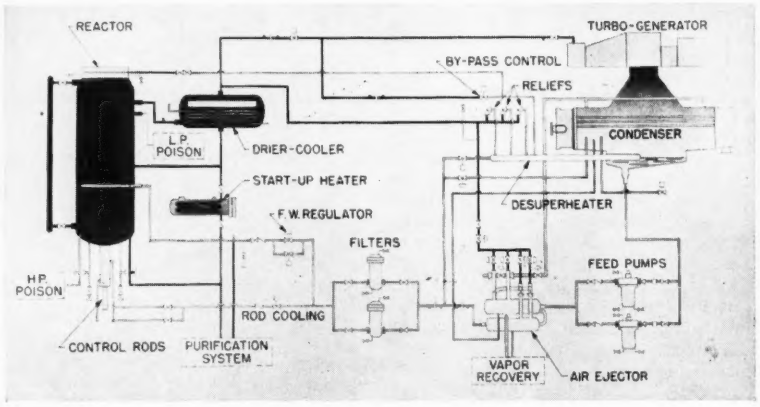


(Left) Inserting a fuel element during criticality experiments.



(Right) Looking down at the reactor core from the top of the pressure vessel.





(Above) Diagram of steam cycle. (Left) Control-rod sleeves and mechanisms underneath the pressure vessel.

mediately below the closure. For refuelling, the top cover plate is removed and replaced by a carrier ring with rotating index plugs turned by means of gears.

The control-rod nozzles, extending nearly 7 ft. below the vessel, were assembled with an angular tolerance of 6 min. to provide against binding of the control rods. Labyrinth seals are provided to guard against leakage.

Shielding

In addition to a boron-stainless steel shield inside the vessel wall, the vessel is surrounded with 3 in. of stainless-steel wool, 3 in. air space and a steel cylindrical tank which serves as an inner form for the concrete shielding and is equipped with cooling coils on its outer side, the coils being covered with lead brick and with a plaster containing ferroboron. Magnetite concrete, with or without steel punchings, and ordinary concrete comprise the rest of the shielding, which has a total radial thickness of 8 ft. 3½ in.

Steam Cycle

Steam is generated at 600 p.s.i. and 488°F, leaving at the top of the reactor and passing to a steam-drier-cooler unit. This consists of a pressure vessel 36 in. in diameter and approximately 6 ft. long, built of stainless steel (also by the B. and W. Co.) $1\frac{5}{16}$ in. thick containing two rows of steam scrubbers of conventional design. The primary purpose of this vessel is to reduce carry-over to the absolute minimum, since radioactive build-up in the turbine will be dependent on water droplets and impurities carried over. It is expected that the steam leaving the reactor will contain about 1% moisture which will be reduced to 0.1% after leaving the drier, with a dissolved solids content of less than 0.001 p.p.m.

In addition, the steam drier performs the additional function of an emergency cooler after a shut-down, and a stainless-steel cooling coil is incorporated, fed from a 15,000-gallon tank of water at a 50-ft. head.

Steam in excess of the turbine demand is by-passed through a spray-type desuperheater into the condenser. A relief valve and two safety valves also discharge into the desuperheater to protect the reactor vessel in case of accidental closure of by-pass and throttle valves simultaneously.

Leakage

One of the most interesting features of the EBWR system is the care and thought that has been applied to the problem of steam containment, all relief valves, etc., discharging into the desuperheater and not to atmosphere. One of the most difficult items is, of course, the H.P. end of the turbine. Figures given by the Allis-Chalmers Manufacturing Co., the contractors for the steam plant, indicate that labyrinth steam from a conventional turbine may be as high as 1,000 lb./day. In this turbine it has been reduced to less than 1 lb./day.

The turbine is a multi-stage impulse unit (one Curtis, eleven Rateau) running at 3,600 r.p.m.

The H.P. gland is of the multiple labyrinth type and is divided into four sections or chambers. The centre chamber is supplied with normal gland steam at approximately 3 p.s.i., while the chamber on the inner side is connected to the eighth turbine stage. The outer chamber is connected to the vapour recovery unit, and operates at a vacuum of approximately 6 in. w.g. Outside this is another chamber to which is supplied dry air at a positive pressure of 6 in. w.g. Other items of equipment, such as throttle valve and governor valve lift, rod packing, etc., are all connected to the same system.

The main condenser is of the divided water-box type, so that in the event of a tube being damaged one-half of the condenser can still be operated. Double tube plates are used, the space between the tube plates being under vacuum. Aluminium tubes are used to avoid contamination of the water with material, that could become radioactive.

Normally, when both halves of the condenser are operating, the sprays in the desuperheater are not used, but they automatically come into operation if steam is dumped when only one-half of the condenser is in use.

An auxiliary heat exchanger is used to preheat the water in the reactor system when starting up; this is heated by steam from the laboratory supply.

At present the reactor is operating with natural circulation and light water. It is probable, however, that forced circulation will be applied at a future date. It is also a part of the research programme to operate with heavy water.

Water Purification

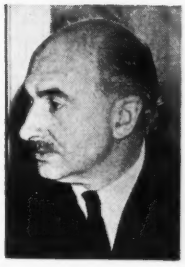
Before feed-water enters the reactor it passes through one of two cotton filters to remove any corrosion and erosion particles. There is also a continuous purification system which removes water from the reactor vessel, passes it through mixed-bed ion exchange filters and returns it with the feed-water.

Enclosure

The main reactor building is a dome-ended cylindrical steel shell 80 ft. in diameter by 119 ft. overal height, 56 ft. being below ground level. The bottom and straight sides are $\frac{5}{8}$ in. thick; the hemispherical top is $\frac{3}{4}$ in. thick. It was built by the Graver Tank and Manufacturing Co. Construction work, which included an excavation 70 ft. deep and 200 ft. in diameter at the top, was by the Sumner Sollitt Co. The consulting engineers for the entire scheme were Sargent and Lundy.

We are indebted to the Argonne National Laboratory of the A.E.C. for the information contained in this article.

Personal



Mr. H. A. Lewis

Mr. C. Flurscheim.

Mr. C. J. Howard.

Mr. D. P. Sayer.

Mr. R. H. Sturges has been appointed managing director and **Mr. R. Purnell** has been appointed to the board of the newly formed subsidiary of Head Wrightson and Co. Ltd., Head Wrightson Teesdale Ltd., **Mr. J. W. Wardell,** managing director, and **Mr. R. B. W. Bolland** to the board of another subsidiary, Head Wrightson Stockton Forge Ltd., **Mr. N. Addison** to the board of Head Wrightson Iron Foundries Ltd. and **Mr. T. H. Stayman** to the board of Head Wrightson Iron and Steel Works Engineering Ltd.

Mr. W. R. Edwards, M.I.Mech.E., has retired from the position of managing director of John Thompson Water Tube Boilers Ltd., but is continuing with the John Thompson Group of companies in a consultative capacity. He is succeeded by **Mr. C. J. Howard,** who for the last 20 years has been London manager and director.

Mr. J. Guthrie and **Mr. J. A. Kilby** have been appointed special directors of Colvilles Ltd.

Mr. C. H. Flurscheim, B.A., M.I.E.E., Mem.A.I.E.E., formerly asistant chief electrical engineer, has been appointed chief electrical engineer of Metropolitan-Vickers Electrical Co. Ltd. He succeeds **Mr. H. West,** managing director of A.E.I.-John Thompson Nuclear Energy Co. Ltd., who will, however, retain his seat on the board of Metropolitan-Vickers as director, electrical engineering. **Mr. A. E. Grimsdale,** B.Sc. (Eng.), formerly special assistant, sales management, has been appointed manager, home sales, with special responsibility for home district offices. **Mr. H. F. Bibby,** B.Sc. Tech., A.M.I.E.E., A.M.I.Mech.E., assistant general manager of Metropolitan-Vickers Electrical Export Co. Ltd., and **Mr. G. H. Jolley,** M.I.Mech.E., principal representative of the Export Co. at Trafford Park, have been appointed to the board.

Mr. B. L. Snow (sales manager) has joined the board of George Mann and Co. Ltd.

Mr. H. A. Lewis, M.B.E., T.D., B.Sc. (Eng.), A.C.G.I., M.I.E.E., A.M.I.I.A., personal assistant to **Mr. E. J. Emery,** managing director of the Domestic Division of Electric and Musical Industries Ltd., has been appointed a director of E.M.I. Sales and Service Ltd. **Mr. J. N. MacLeod** and **Mr. C. Metcalfe** have been appointed directors of the company.

Mr. Hugh R. Ryers, special director and sales manager of William Beardmore and Co. Ltd., has been appointed a director of the company.

Sir Arthur Whitaker, K.C.B., M.Eng., M.I.C.E., has been elected president of the Institution of Civil Engineers following the death of Mr. H. J. F. Gourley. Sir Arthur was formerly the senior vice-president of the Institution.

Mr. John Eden, until recently sales and contracts manager for Birtley Engineering Ltd., has been appointed contracts manager of W. P. Butterfield Ltd.

Mr. D. P. Sayers, B.Sc., M.I.E.E., M.I.Mech.E., M.Amer.I.E.E., has been appointed chief contracts officer to the Central Electricity Authority in succession to **Mr. F. W. Smith** who has retired. For the past three years Mr. Sayers has been deputy chairman of the Midlands Electricity Board.

Sir Fred G. Thorpe, M.C., E.D., has joined the board of Vickers Australia Pty. Ltd., which was formed to hold the shares of companies in Australia owned by Vickers Ltd. **Mr. E. E. Kennaird,** sales manager, has joined the board of Cooke, Troughton and Simms Ltd., and **Mr. H. F. Judd,** A.I.E.E., general sales manager, the board of Ioco Ltd. Both these companies are members of the Vickers Group.

Mr. Edgar Stewart Lane has retired from his position as northern area sales manager of the Medical Division of British Oxygen. He is succeeded by Mr. F. B. Stephens, formerly assistant area sales manager.

Mr. E. Springthorpe, chief draughtsman in the constructional steelwork department, **Mr. C. N. Bradshaw,** personnel and administration department, **Mr. E. Wolstenholme,** assistant to the London director, **Mr. G. Page,** manager of the export department, **Mr. R. Hadfield,** manager of the foundry supplies and refractories side, and **Mr. A. Kissack,** of the machine tool section, have all been appointed local directors of Thos. W. Ward Ltd.

Mr. Raymond Dorrington Bangay, foreign manager of Marconi's Wireless Telegraph Co. Ltd., has retired after more than 54 years with the company. Mr. Bangay will, however, continue to serve the company on special projects in connection with overseas business.

Mr. J. M. Phelan has been elected chairman of the board and president of Nuclear-Chicago Corporation, formerly known as Nuclear Instrument and Chemical Corporation. **Mr. H. C. Young** has been appointed export manager of the corporation.

Mr. J. Roy Gordon has been elected executive vice-president of The International Nickel Company of Canada Ltd. and also executive vice-president of The International Nickel Co. Inc., the company's U.S. subsidiary.

Sir Ben Lockspeiser has been re-elected president of the Council of the European Organization for Nuclear Research (CERN).

Rear-Admiral G. A. M. Wilson has taken over full responsibility in the Admiralty for nuclear propulsion with the title Rear-Admiral Nuclear Propulsion. He will also be deputy engineer-in-chief (Nuclear Propulsion). Rear-Admiral Wilson was previously deputy engineer-in-chief for Fleet Maintenance and Administration.

Mr. Lyman A. Bliss has been appointed president of Union Carbide Nuclear Co., a division of Union Carbide and Carbon Corporation. He succeeds **Mr. K. Rush,** a vice-president of the parent corporation.

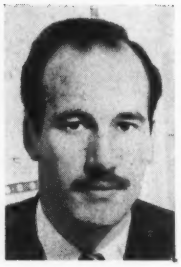
Mr. K. W. Trevatt has been appointed representative of the Cambridge Instrument Co. Ltd. in the Liverpool area in succession to **Mr. W. J. Cole,** who has retired.

Air Commodore J. A. Hawkings, C.B.E., R.A.F. (Retd.), M.I.Mech.E., A.F.R.Ae.S., has been appointed controller of the new research and development division which has been established by the Pyrene Co. Ltd.

Mr. F. E. Barritt, works manager of K.D.G. Instruments Ltd., and **Mr. L. R. Pullen,** sales manager, have been appointed technical directors of the board of the company.

Mr. F. Clark, M.B.E., has been appointed manager of the sales technical service department of British Oxygen Gases Ltd., **Mr. H. J. Vine** superintendent, photographic section, **Mr. L. B. Smith** superintendent of the general service section and **Mr. A. W. Stones** manager of the Western district of the company at Cardiff. Mr. Stones succeeds **Mr. J. E. Clark,** who has accepted an appointment with British Oxygen Wimpey Ltd.

Mr. A. H. Johnston.



Mr. J. F. Hendrie.

Mr. M. G. McBride.

Mr. J. F. Hendrie, formerly a technical representative for the equipment division of Mullard Ltd., has been appointed sales manager of the nucleonic and electronic department of Dynatron Radio Ltd.

Mr. M. G. McBride, B.Sc., A.M.I.E.E., has rejoined Sangamo Weston Ltd., as contracts manager of the instrument division. Since 1952 Mr. McBride has been chief engineer with Record Electrical Co. Ltd., previously being employed in the engineering department of Sangamo Western Ltd.

Mr. A. H. Johnston has been appointed a nucleonics sales engineer of Ekco Electronics Ltd. and will be based at the company's Manchester offices. Mr. Johnston was formerly an electronics inspector with the Ministry of Supply (I.E.M.E.).

Mr. Bruce Wilkinson, formerly managing director of Electronic Tubes Ltd., has joined the Plessey Co. Ltd. as divisional manager of the Swindon components division.

Dr. W. I. Pumphrey, Ph.D., M.Sc., research manager of Murex Welding Processes Ltd., has been awarded the degree of D.Sc. in industrial metallurgy by the University of Birmingham for his work on hardenability, the transformation of steel during continuous cooling and the metallurgy of welding.

Professor Dr. Ing. Walther Bauersfeld has been awarded the 1957 James Watt International Medal by the Council of the Institution of Mechanical Engineers in recognition of his work as a scientist, inventor and successful organizer, particularly in the application of precision engineering in the field of optics.

Dr. Arthur E. Ruark, Professor of Physics at the University of Alabama, has been named chief of the controlled thermo-nuclear branch in the Division of Research of the U.S. Atomic Energy Commission. He succeeds **Dr. Amasa Bishop,** who recently became the A.E.C.'s technical representative at the U.S. Embassy in Paris. **Dr. Paul C. Fine** has been appointed director of the Commission's Office of Operation, Analysis and Planning.

Mr. L. F. Matthews, formerly of the Ekco Car Radio Sales Division, has been appointed sales manager of Egen Electric Ltd.

Mr. G. W. Hall, vice-chairman and managing director of the Fairey Aviation Co. Ltd., has been appointed acting chairman following the death of Mr. R. T. Outen.

Mr. Gale Young, formerly vice-president and technical director, has been appointed vice-president and co-executive with Mr. J. R. Menke of the Nuclear Development Corporation of America. Succeeding Mr. Young is **Dr. Gerald Goertzel,** formerly assistant technical director. Dr. Goertzel has also become manager of technical operations. **Mr. A. M. Zais,** general business manager, has been appointed manager of administrative operations and acting controller, and **Mr. W. A. Hamilton,** formerly director of planning, manager of contract operations. **Mr. Willard S. Mott,** formerly administrative engineer, has become manager of contract administration.

Dr. Thomas H. Pigford, associate professor of nuclear and chemical engineering at Massachusetts Institute of Technology, has been appointed chairman of the department of reactor engineering of General Atomic's John Jay Hopkins Laboratory for Pure and Applied Science, a division of General Dynamics Corporation.

OBITUARY

It is with deep regret that we have to announce the deaths of **Mr. Roland T. Outen,** chairman of the board of the Fairey Aviation Co. Ltd., and of **Air Vice-Marshal Oswyn George W. G. Lywood,** C.B., C.B.E., L.M., a director of Automatic Telephone and Electric Co. Ltd.

MEETINGS TO NOTE

March 5.—Institution of Civil Engineers: "Behaviour of Radio-isotopes in Sewage Treatment, and the Disposal of Radioactive Wastes to Sewers", A. W. Kenny.

March 5.—Institute of Metals (Oxford local section, at Cadena Café, Cornmarket Street): "The Writing of Scientific Papers", W. Hume Rothery.

March 6.—I.E.E. (Tees-side sub-centre, at Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough): "Atomic Power Stations", D. F. Welch.

March 7.—Institute of Metals (London): "Gas in Light Alloys", C. E. Ransley.

March 7.—Institute of Metals (Leeds Metallurgical Society, at the University): "The Study of Wear and Lubrication using Radio-isotopes", P. J. E. Forsyth.

March 8.—Risley Nuclear Engineering Society: "An Outside View of Nuclear Power", Prof. J. Diamond.

March 8.—I.E.E. (North - eastern centre, at the Liberal Club, Newcastle upon Tyne): Informal lecture on "Graphite Manufacture", R. C. Newman.

March 11.—Institute of Metals (Scottish local section, at 39 Elmbank Crescent, Glasgow): "Production and Uses of Rare Metals", J. C. Chastow.

March 12.—I.E.E. (in conjunction with the B.N.E.C.): "An Analogue Computer for Nuclear Power Studies" and "The Application of Analogue Methods to Compute and Predict Xenon Poisoning", G. J. R. McLusky.

March 12.—Institute of Metals (South Wales local section, at Department of Metallurgy, University College, Swansea): "Clad Metals", Prof. A. R. E. Singer.

March 14.—Institution of Chemical Engineers (North-western branch, at Reynolds Hall, College of Technology, Manchester): "Disposal of Long-lived Fission Products", J. R. Grover.

March 18.—Institute of Metals (Sheffield local section, at Engineering Lecture Theatre, Sheffield University): "Materials of Construction in the Heavy Chemical Industry", F. M. Keating.

March 19.—I.E.E. (East Midland centre, at College of Arts and Crafts, Nottingham): "The Control and Instrumentation of a Nuclear Reactor", A. B. Gillespie.

March 21.—Institution of Mining and Metallurgy (at the Geological Society, Burlington House): "Separation of Uranium and Copper during the Acid Pressure Leaching of Sulphidic Uranium Ores", J. Halpern and F. A. Forward.

March 26.—Society of Instrument Technology: "Process Development and Plant Design—the role of instrumentation with particular reference to the application of computers", S. T. Lunt.

March 29—Manchester Association of Engineers: "Nuclear Energy", Prof. J. Diamond.

March 29.—I.E.E. (Southern centre, at the South Dorset Technical College, Weymouth): "Nuclear Power", H. A. Roberts.

March 29.—Institution of Mechanical Engineers: "Rotary Shaft Seals—the sealing mechanism of synthetic rubber seals running at atmospheric pressure", E. T. Jagger.

April 2.—Institution of Chemical Engineers (London, at the Royal Institution), B.N.E.C. meeting: "The Aqueous Homogeneous Reactor", R. Hurst.

World News

At top of page: A heat exchanger, the first of eight, on its way to Marcoule from the La Corneuve works of the Société Française des Constructions Babcock et Wilcox. Weighing 108 tons, 103 ft. long and 11 ft. 6 in. in diameter, the vessel averaged 1½ miles per hour for the journey, which involved detours totalling 800 miles.

(Above) Delegation from the European Atomic Energy Community in the United States. Left to right: Sr. Giordani (Italy), M. Armand (France), Mr. Dulles, Herr Etzel (West Germany) and M. Kohnstamm (Luxembourg).

INTERNATIONAL

Vienna has been selected for the first general conference of the International Atomic Energy Agency. This was decided by a preliminary meeting of 18 nations at U.N.O. headquarters in New York.

Concrete proposals for joint European undertakings have been announced by O.E.E.C. The main project is a chemical processing plant for irradiated fuel, which would be owned and administered by an international company. No site has yet been chosen. O.E.E.C. also plans five experimental reactors, including a liquid-metal fuelled, a homogeneous aqueous, a materials testing, a boiling water and a fast breeder.

GREAT BRITAIN

Insurance representatives of twelve nations held a conference in London about mid-February to exchange views on collaboration between world insurance markets concerning the particular problems of nuclear reactor insurance.

The second reactor at Calder, criticality of which was announced in *Nuclear Engineering* for January, is now on load. In the eight months' operation of No. 1 reactor, only two failures of fuel elements had been reported.

The Government is to set up a national institute for research in nuclear science to provide facilities and equipment beyond the resources of individual universities. Finance is expected to be by means of grants by the A.E.A.

Titanium metal basic prices have been cut by 10%, it is announced by I.C.I. Ltd.

The public inquiry on the Hunterston site, for the power station that the G.E.C. Simon-Carves group is to build for the South of Scotland Electricity Board, ended on February 13.

AUSTRALIA

The South Australian Government is stated to be seeking a loan from the U.S. Export-Import Bank for the purchase of an American power reactor to be located at Mount Gambier.

BELGIUM

The nuclear power plant which was to have been part of the 1958 Brussels Exhibition is now to be erected at Mol. It is understood that local objections were raised to the original site, which was to have been at Laeken.

A high-flux materials testing reactor is to be built at Mol. The heat output will be some 25 MW.

CANADA

Investigation of improved methods of sulphur recovery from sulphur dioxide produced in ore-roasting operations is the object of an agreement between the Texas Gulf Sulphur Co. and the International Nickel Co. of Canada Ltd.

DENMARK

The new research centre at Riso is expected to be constructed before the end of the year. Atomics International Inc. are supplying a zero energy boiling-water research reactor. A 5-MW research reactor is also being purchased in the U.S.A.

FRANCE

France's fifth reactor, E.L.3, is practically complete. It is a materials testing reactor of the heavy-water type, with a heat output of 15 MW.

The "France", a 55,000-ton luxury liner due for completion in 1961, is being designed so that normal boilers can be replaced by nuclear plant.

A training establishment for nuclear submarine crews is to be established at Cherbourg.

GERMANY

West Berlin is to have a 50-kW research reactor. It is to be built by A.M.F. Atomics Inc.

Heavy water is to be produced during the latter half of 1957 by the Hoechst chemical works at Frankfurt, one of the successors to the I. G. Farben group. Heavy-water production will be combined with carbide manufacture.

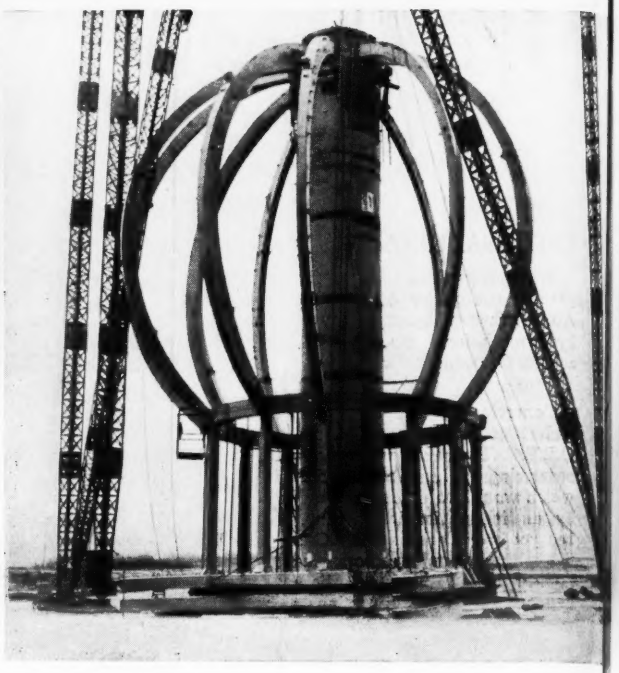
GREECE

A contract for a research reactor to be located near Athens has been placed with A.M.F. Atomics Inc. Construction is expected to commence early in 1958.

HOLLAND

A group of Dutch nuclear engineers has been granted some 5 million guilders (£500,000) for industrial development.

(Above) One of the exciting coils for the CERN proton synchrotron alongside the impregnating vessel at the works of Ateliers Constructions Electriques de Charleroi.



(Right) The first sphere of the "Atomium" under construction in Brussels in preparation for the 1958 World Fair. When completed, it will be a representation of a molecule of nine atoms, rising more than 300 ft. into the air. The upper atoms, which will be reached by stairways, will contain restaurants and exhibition stands.

INDIA

The Trombay reactor has been formally opened by Mr. Nehru, Prime Minister of India at the inauguration of the Asian Atomic Centre. Criticality of this reactor was announced in *Nuclear Engineering* for September, 1956. It has officially been named "Apsara" (literally "water nymph").

An increase of 3,500 MW in India's power output, forecast for the second five-year plan (due to end in 1960-61) would include a 140-MW nuclear station, according to the Minister of Irrigation.

JAPAN

A five-year plan for nuclear power totalling 3,000 MW has been announced.

LATIN AMERICA

Three reactors have been ordered from the I.G.E. Co. Two are 12.5-MW boiling-water units, the third being a 3-MW swimming-pool reactor for the Venezuelan Research Centre near Caracas.

Argentina is negotiating a contract with General Electric (U.S.) for an experimental reactor.

A pool-type reactor manufactured by the Babcock and Wilcox Co. is in process of dispatch. Intended for the University of Sao Paulo, it is rated at 5 MW, using 20% enriched uranium.

NEW ZEALAND

Uranium reserves have been discovered in the Buller Gorge (South Island). Samples of the ore assay from 2-5% and, according to reports, the deposits are valued at £10-20 million.

NORWAY

Six shipping companies are to co-operate in designing a nuclear-propelled tanker.

A/S Noratom, a new company, is being formed to promote the industrial use of nuclear energy, undertaking market analyses and even the operation of reactors.

Inter-Scandinavian co-operation in nuclear research will be a major item at the Helsingor meeting of the Northern Council. A Scandinavian institute for the study of nuclear physics and a Scandinavian research centre have been proposed.

An agreement with Britain is shortly expected under which Britain will deliver uranium to Norway.

SOUTH AFRICA

Basic price of copper from Roan Antelope and Mufulira Mines was cut by £20 a ton on February 1 for U.K. customers.

SWITZERLAND

Expenditure on nuclear energy, according to Board of Trade sources, is approximately 1s. per head of the population. This compares with £1 7s. in Great Britain and £6 15s. in the U.S.A.

U.S.A.

The EBWR (Experimental Boiling Water Reactor) which had a test run on December 29, as previously announced, was officially placed on full power operation at 2.30 p.m. on February 9. A brief account of this plant is given on page 121.

The public inquiry into the proposed "Enrico Fermi" fast reactor at Monroe, Michigan, has been adjourned until March 4. A brief description of this project is given on page 112.

Oak Ridge National Laboratory has completed ten years of isotope production and distribution. This laboratory is operated for the A.E.C. by Union Carbide International Inc.

The gaseous diffusion plant at Paducah, Kentucky, damaged by fire some time ago, has now been restored to 80% production, following repairs by the Malan Construction Corporation of New York. Fire damage was estimated at 2 million dollars.

Isopropylbiphenyl, a new derivative of biphenyl, which has received favourable reports as an organic moderator, is now being supplied in pilot-plant quantities by the Monsanto Chemical Co. in St. Louis.

The atomic submarine *Seawolf* commenced trials recently, the previously-

(Right) The heaviest component of the Sodium Reactor Experiment (SRE), the 75-ton loading face shield, being fitted into the top of the nuclear reactor recently. Eighty-one holes through the shield provide access for removing and replacing fuel elements, and operating control and safety rods. In positioning the shield over the core, the holes were aligned with the fuel element channels in the core to 1/64 in. The SRE is being built by Atomics International, a division of North American Aviation Inc. A brief description appeared in *Nuclear Engineering* for February.

(Below) The atomic submarine *Seawolf* on trials.

reported failures having been overcome by by-passing the superheater. The reactor is of the liquid sodium type, unlike the pressurized-water type used in *Nautilus*. The displacement of the *Seawolf* is 3,260 tons, the length being 326 ft. and the beam 30 ft. A speed of over 20 knots when submerged is anticipated and the range is 25,000 miles.

Fifth session of the A.E.C.'s International School of Science and Engineering at the Argonne National Laboratory will include 64 scientists and engineers, of whom 51 are from 25 countries overseas.

Standards for protection for ionizing radiation, effective as a Regulation from February 28, 1957, have been established by the A.E.C.

Manganese production from domestic ores is the object of a new company, U.S. Manganese Corporation, jointly formed by Vitro Corporation, Sheer-Korman Associates Inc. and Great Divide Mining and Milling Corporation, the latter owning considerable deposits of rhodonite, a highly refractory manganese-rich ore hitherto not considered suitable for commercial exploitation.

Uranium stockpiling in the U.S. last year was the equivalent of 10,000 million tons of coal, according to Dr. K. Pitzer, dean of the college of chemistry of the University of California.

A permit has been issued for a pool-type research reactor to be constructed by A.M.F. Atomics Inc. in Plainsboro' Township, New Jersey.

Radiation check on crew of "Nautilus" shows average of 173 mr. for the year—less than the maximum dosage for one week laid down by the National Committee for Radiation Protection. Individual maximum for the year was approximately 1,400 mr.

Initial processing of uranium-silver ore has been announced by Western Gold and Uranium Inc. at Silver Reef, near Leeds, Utah, where a new plant has been erected. Final processing (after extraction of the silver) will take place at the Vitro Uranium Co.'s mill at Salt Lake City.

Insurance coverage for nuclear plants is contemplated by three major U.S. syndicates. Two of them are the Nuclear Energy Property Insurance Association and Nuclear Energy Liability Insurance Association, the latter consisting of more than 100 insurance companies. A third syndicate is said to be in the course of formation.

A joint development programme for the nuclear propulsion of merchant ships has been announced by the A.E.C. and the U.S. Maritime Commission. Although it is stated to be a long-range programme, it is understood that contracts have been placed with six U.S. manufacturers for four reactor systems.

The Atomic Exposition and Nuclear Congress to be held in Philadelphia from March 11 to 15 will include a working reactor. The A.E.C. has given notice of its intention to license Aerojet-General Nucleonics to transfer one of their 100-milliwatt research reactors to the exhibition, and plans include bringing it up to power approximately ten times a day.

A sub-critical assembly is to be used at the Wright Patterson Air Force Base in Ohio for training nuclear engineers. The A.E.C. has approved the loan of 5,500 lb. of uranium for this purpose, which will be the seventeenth of its type.

U.S.S.R.

Russia is to have five nuclear power stations in operation between 1958 and 1960, according to a Moscow report. Capacities are said to range between 400 and 600 MW.

The hull of the 16,000-ton ice-breaker *Lenin*, which is to be nuclear propelled, will be launched by November of this year, according to a Moscow report.

YUGOSLAVIA

Yugoslavia's first reactor will commence operation at Vina, near Belgrade, before the end of 1957, according to a report received early in February.

Industrial Notes

Head Wrightson and Co. Ltd. announce the virtual reorganization of the whole of the Head Wrightson Group following the formation of the following subsidiary companies: Head Wrightson Teesdale Ltd. (at present the engineering division of Head Wrightson and Co. Ltd.), Head Wrightson Iron and Steel Works Engineering Ltd. (at present the McKee division of Head Wrightson and Co. Ltd.), Head Wrightson Stockton Forge Ltd. (at present the Stockton Forge division of Head Wrightson and Co. Ltd.) and Head Wrightson Iron Foundries Ltd. (at present the iron foundries division of Head Wrightson and Co. Ltd.).

Expansion of the subsidiary companies of **English Steel Corporation Ltd.** is to be made possible by a new 500-acre site at Tinsley Park, Sheffield, on which work commenced at the end of January. First works on the site will be for the English Steel Spring Corporation Ltd. and is expected to be completed during 1958.

Air Control Installations Ltd., of Ruislip, Middlesex, have opened a new branch office at Cross House, Westgate Road, Newcastle upon Tyne 1 (telephone 28861).

Loughborough College of Technology announces that its main course in work study, formerly taking ten weeks, has now been rearranged into shorter, self-contained courses to assist companies with the difficulty of releasing trainees for ten consecutive weeks, and enabling them to spread the training period on a "sandwich" basis.

Borax Consolidated Ltd. have acquired research laboratories to provide facilities for some 50 chemists at Tolworth in Surrey. These, together with those at Belvedere, will enable a considerable expansion in their programme of research in the boron chemistry field.

W. V. Zinn, the consulting engineer, has transferred his Liverpool branch to Ranelagh House, Ranelagh Street, Liverpool 1 (telephone ROYal 4531).

The Du Pont Co. (United Kingdom) Ltd. is to proceed with its proposed plant for neoprene manufacture near Londonderry and construction will commence about the middle of the year. An adjacent site of 50 acres has been acquired by Carbide Industries Ltd., a subsidiary of the British Oxygen Co. Ltd.

Midland Silicones Ltd. announces that its North-eastern Area sales office has moved to 5/7 New York Road, Leeds 2 (telephone 26768).

R. A. Stephen and Co. Ltd. of Mitcham is to work in close collaboration with Isotope Developments Ltd., Beenham Grange, Berks, in the manufacture of nuclear instruments.

British Insulated Callender's Cables Ltd. have moved their Southampton branch to 16/17 Vincent's Walk, Southampton. The telephone number (Southampton 26176) remains unchanged.

PUBLICATIONS

Synthetic Rubbers and Chemicals.—Brochure entitled "Du Pont Elastomers, a Management Report" received from Durham Raw Materials Ltd., of 1-4 Great Tower Street, London, E.C.3, who are the sole selling agents for E. I. du Pont de Nemours and Co. Inc. Also received is Durham Raw Materials Ltd.'s own catalogue of products available.

Nickel and its By-products.—The first issue of the *Mond Magazine*, published by the publicity department of the Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1, contains interesting articles on subjects as diverse as palladium jewellery, stained-glass windows and trench excavation. This journal, which is attractively produced and has a number of colour illustrations, is intended to supplement the *Nickel Bulletin* in a wider field; it will not supersede it.

Air-break Switchgear.—A brochure (in English) from the Ateliers de Constructions Electriques de Charleroi covering "Blocacec" l.v. distribution units of the draw-out type up to 550 V 4,000 amp. with h.r.c. air-break circuit breakers. The design is exceedingly compact. Another brochure describes metal-clad air-break switchgear for 6- and 15-kV service up to 500 MVA breaking capacity.

Pneumatic Tool Lubrication.—A 44-page booklet published by the Mobil Oil Co., Caxton House, Westminster, London, S.W.1, describes the lubrication of all types of pneumatic tools and equipment, and the problems peculiar to compressed-air operation.

Silver-zinc Accumulators. — Small lightweight batteries of the silver-zinc type are described in a catalogue received from Venner Accumulators Ltd., of New Malden, Surrey.

Silicone Paints.—The peculiar properties of silicone-based paints in resisting high temperatures and repelling moisture, together with a list of British paint manufacturers using silicones, are described in a folder from Midland Silicones Ltd., of 49 Park Lane, London, W.1.

Freight Services.—The Northern Ireland Development Council has issued a 56-page booklet for the benefit of industrialists who are considering the location of a factory there, to describe the available freight services.

Platinum.—Creep properties of platinum metals and alloys, the use of platinum for bursting discs in chemical processes, abstracts and patents are amongst the contents of *Platinum Metals Review*, a new quarterly journal published by Johnson, Matthey and Co. Ltd., of Hatton Garden, London, E.C.1.

Computing Service.—The Elliott Computing Service is amongst the topics discussed in No. 37 of the *Elliott News* published by Elliott Bros. (London) Ltd., Century Works, London, S.E.13.

Electrodeposition of Metals.—A new reference folder issued by Fescol Ltd., of North Road, London, N.7, contains, amongst other reference materials and leaflets, a 29-page book on the Fescol process, with a considerable amount of technical information on nickel and chromium, with corrosion - resistant tables, and a list of services available.

Non-destructive Testing.—No. 4 of the *SS News* published by Solus-Schall Ltd., 15 Clipstone Street, London, W.1, is devoted to non-destructive testing.

Storage Trays.—Kabi midget storage trays for bench assembly work are covered in a leaflet issued by Precision Components (Barnet) Ltd., of 13 Byng Road, Barnet, Herts.

Machine Tools.—Toolmaking, precision machining and the rebuilding of machine tools are described in a leaflet from Nash and Hodge Ltd., precision engineers, of Summit Works, Woodbridge, Guildford, Surrey.

Nickel.—Welding of Nimoply 75, a composite metal sandwich composed of Nimonic 75 bonded on both sides of a copper inter-laver, is one of the features of No. 42 of *Wiggin Nickel Alloys*, published by Henry Wiggin and Co. Ltd., of Thames House, Millbank, London, S.W.1.

Continuous Casting of Bronze.—The ENCON continuous casting of bronze and gunmetals is described in a publication issued by Enfield Rolling Mills Ltd., of Brimsdown, Enfield, Middlesex.

Air Filters.—The Sturtevant Engineering Co. Ltd., of Southern House, Cannon Street, London, E.C.4, has issued a third edition of its booklet dealing with the Precipitron filters for air or oil mists.

Organic Heat-transfer Medium. — Monsanto Chemicals Ltd., of Monsanto House, 10-18 Victoria Street, London, S.W.1, have issued a technical service bulletin, "Diphenyl for Heat Transfer", giving the physical properties and tables of heat-transfer data from 29-in. vacuum to the critical pressure of 592.3 p.s.i.

Orbits in Industry

This "first in the world" challenge, to which reference was made last month, has been repeated, it would appear, according to a Reuter message from Los Angeles, stating that Mr. Robin McAlpine had made the same claim. We ourselves have not seen the Bradwell site since the first turf was removed, so that it is not possible to say what progress has been made, but Berkeley, as indicated elsewhere in this issue, is not exactly like the vicarage garden on a summer afternoon. Also, the inquiry concerning the Hunterston site is now concluded, and if the decision should be favourable one feels that the third group would not lose much time. The race should provide some exciting moments during the next few years, to say the least.

March of Progress

A short comment on that word "favourable" might not be out of place. It means, of course, favourable to the pro-Hunterston party. Now that the inquiry is closed and no words of ours can affect the issue either way, it is possible to say something about the march of progress. It is difficult not to sympathize with the "antis" in their efforts to preserve their country-side (Bradwell, incidentally, was a yachtsman's paradise, well off the beaten track, and there were few more peaceful spots in this country than that narrow, winding creek behind Peewit Island) and it is practically impossible to say anything that is not horribly trite, but one can only console oneself with the thought that when the Dutch engineers started draining the Fens in the reign of Charles II, there was probably an outcry about the disfigurement of the countryside by new-fangled windmills.

Small Reactors

The news about the Humphreys and Glasgow-Alco agreement was released too late last month to make more than a short news item. There was some surprise when, in the course of the announcement, the estimated cost of generation was given as 1½d.-2d. per unit. Many of those present at the conference seemed to feel that this was an uneconomic price, and it was left to Professor Kay of Imperial College, to restore a sense of proportion. He pointed out something that many fail to realize: small stations cannot be compared with large stations and that, even in the field of conventional fuels, comparing a small isolated power plant with the C.E.A.'s top-of-the-table stations one would get a difference of the same order. Since Professor Kay had no affiliation with either side, but was present as an impartial observer, his words carried even more weight than those of the principals concerned.

While on the subject of a sense of proportion, however, let us not be unduly impressed by the performance of *Nautilus*. As a marine achievement, 60,000 miles without refuelling is fantastic—in terms of power station steaming time, it is not so impressive. At an average speed of 20 knots, this represents 3,000 hours' operation or just over four months. This is not intended to belittle the capabilities of the small reactor, it is merely a suggestion that large figures require a little interpretation at times: they may be fantastic against one background and meaningless against another.

Significant Decade

The I.E.E.'s Faraday lecture needs no introduction to engineers, nor, in fact, to an ever-growing section of the general public; while the subject itself, "Nuclear Energy in the Service of Man", was of more than passing interest at the present time. Even more interesting, however, was the fact that Dr. T. E. Allibone, who gave this year's Faraday lecture, gave another one just over ten years ago with the title of "Atoms, Electrons and Engineers". Those attending both (and there must have been many, for the Faraday lecture is notoriously habit-forming) must have been struck by the almost fantastic progress in a single decade. In 1946, atomic energy meant The Bomb, although a handful of writers spoke vaguely on the possibilities of its peaceful uses: today, every schoolboy chatters glibly about atomic power—and some of them even understand it. Nuclear energy is no longer the playground of the physicist, it is a branch of engineering in its own right.

Most gratifying of all, however, is that in 1946 Dr. Allibone's paper spoke of ". . . one pile now being contructed at Oak Ridge, Tennessee, to operate at a high temperature to provide heat for an electric generating station. . . ." There was no mention of anything of the sort being even contemplated in Britain. Ten years later, we opened Calder Hall.

Data Processing

An interesting postcript to the "Tell it to the Machines" note in February was the arrival on the day of publication of the news that the Radio Communication and Electronic Engineering Association is forming a section dealing specifically with electronic data processing. This will probably interest many manufacturers of computer equipment and input and output devices who are not at present members of the Association, and would be interested in membership of this section only. Chairman of the section is Mr. C. Metcalfe, managing director of E.M.I. Electronics Ltd.

Didoettes?

News from the U.S. indicates that there is now a commercial irradiation service available, using a source of cobalt-60, for treatment of customer's own materials ". . . by contract or otherwise. . . ." Once irradiation becomes really fashionable, so that even the cookery recipes (from, of course, Mrs. Beta's Cookery Book) read ". . . garnish with alpha particles . . ." there will be a wide public demand for this type of service. As something seems to tell us that do-it-yourself kits will never really catch on with the average housewife (however much she may wish to try that new Isotope Sauce that everyone is talking about), the obvious solution is an extension of the launderette idea, where she and her friends could sit and chat, while watching through the glass windows (high-lead, of course) their food revolve in tumbling baskets (". . . Mum's down at the Cobaltium, we're 'aving irritated steak today. . . ."). On the other side of the establishment would be the gardeners, who have brought their seeds (". . . Bill's grown a tulip with a stem so short that the flower's *underneath* the bulb. . . . They say that blue grass they grow in Kentucky is done with carbon-14—I've brought a barrowload of soot. . . ."). But food, of course, would be the prop and mainstay of the place. If any enterprising type is thinking of starting a Didoette, the following suggestion is offered (for, of course, the usual royalty). Lay on mixed radiation of gamma and infra-red, so that the grub gets cooked at the same time. That should pack 'em in.

"Tangent"

"NUCLEAR ENGINEERING" BY POST

If at any time you find difficulty in obtaining a regular copy of this journal from a newsagent or bookstall, it is as well to remember that it can be posted direct to any address in the world for the inclusive price of 42s. ($7) a year. Subscription orders can be handed to most newsagents or bookstalls, or they can be sent to the Publishers, Temple Press Ltd., Bowling Green Lane, London, E.C.1, England.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 759,900. Production of uranium. R. P. Linstead, F. M. Burstall and T. V. Arden. To: U.K. Atomic Energy Authority.

This refers to the separation of uranium compounds from compounds of other metals, especially by treatment of aqueous solutions containing uranium and other metals. Selective precipitation is effected by adjustment of the pH and control of the anions and the oxidation state of the metals. To an aqueous solution containing uranium and copper and/or aluminium is added a soluble phosphate or arsenate in quantity sufficient to combine with all the uranium; the pH of the solution is adjusted to 2.5 by an alkali. Where the atomic ratio of aluminium to uranium exceeds 1:1, amonium phosphate or sulphate may be added in quantity sufficient to combine with all the uranium and aluminium. The pH is then adjusted by means of an alkali to 1.8 to 2.0 to precipitate uranium. There are further modifications possible and the relevant values are given in the specification.

B.P. 760,191. Sulphur-dioxide leaching of uranium-containing material. To Minister of Mines and Technical Surveys of Canada (Canada).

This is a process involving low reagent and equipment cost, particularly suitable for the treatment of low-grade ores (pitch-blende) or mill tailings. Finely divided material containing uranium, at least partly in tetravalent form and free from metallic iron, is leached with an aqueous solution containing sulphur dioxide in the presence of a soluble ferric iron salt, a soluble manganese salt or mixtures thereof and with aeration of the solution. The amounts of salts required and the rate of aeration should be sufficient for the oxidation of the tetravalent uranium to the hexavalent state. In order to precipitate the uranium from the leach solution, the pH of the solution is adjusted to about 1.25 and iron powder is added in the presence of a precipitant (soluble phosphates, arsenates or fluorides). As free iron should not be present in the initial material, any such iron should be removed during the grinding of the material by magnetic separation, otherwise premature precipitation may be caused.

B.P. 763,667. Method of and apparatus for measuring the thickness of materials. To: Exatest Ges. für Messtechnik m.b.H. (Germany).

The thickness of hot-rolled sheet metal is controlled by electromagnetic radiation sufficiently penetrating so as to be scattered by the electrons of the material. This secondary scattered radiation is proportional to the thickness of the material. Cobalt and cæsium isotopes are suitable, and of particular value is the positron-radiating isotope of sodium Na 22.

B.P. 763,865. Production of radioactive iodine-131. C. C. Evans and J. Stevenson. To: U.K. Atomic Energy Authority.

Tellurium in a tubular silica container is irradiated with thermal neutrons in a nuclear reactor. The container is then placed in a silica vessel in an electric furnace and heated above boiling point. The iodine-131 is distilled off and collected in aqueous caustic alkali. Thus the production itself is carried out in a single step, capable of automatic control and without production of radioactive effluent.

B.P. 764,285. Ternary zirconium alloys. To: United States Atomic Energy Commission (U.S.A.).

A tin-containing zirconium alloy of high tensile strength, at elevated temperatures, high ductility and good corrosion resistance is obtained by incorporating a small amount of molybdenum. The best alloys contain between 1.8 and 4.5% tin and between 0.4 and 3.3% molybdenum. High strength and hot hardness are shown by alloys produced by arc-melting, but induction-melting also gives excellent results. Used for constructional purposes and chemical equipment exposed to high temperatures and corrosive fluids.

B.P. 764,337. Treatment of materials by electronic bombardment. M. C. Crowley-Milling. To: Metropolitan-Vickers Electrical Co. Ltd.

High-energy electron beams (produced, for example, by a linear accelerator, a Van de Graaff generator, a betatron) are capable of penetrating substances to a considerable depth, thereby effectively destroying living organisms (bacteria). For uniform irradiation, an elongated cross-sectional shape of the beam across which the material will be moved is desirable. The beam is produced in a closed chamber, passes through a window (metal foil) and is then subjected to a magnetic field, causing the beam to traverse a curved path and to spread laterally in the plane of curvature.

B.P. 764,575. Gamma-ray absorptive glass, To: Corning Glass Works (U.S.A.).

For windows in concrete protective walls for observing the manipulation of radioactive substances by remote control. Observation windows are usually made up as glass cells of requisite thickness containing a 78% aqueous solution of zinc bromide. The glass used is a conventional barium silicate glass of a density of about 2.7 g/cc containing CeO_2 to prevent undue darkening by the gamma radiation. Sudden loss of the protective solution by accidental breakage constitutes the very serious hazard of fatal exposure of the observer to radiation. With increased intensity of the radiation, "heavy" concrete of a density of about 3.2 g/cc (ordinary concrete= 2.5) is used and the window should have the same absorption as this concrete and be transparent in thicknesses up to 5 ft. or more, which makes the problem still more difficult. Conventional high-density silicate glasses containing PbO or PbO and BaO are highly absorptive, but their content of CeO_2 to prevent darkening makes the transmission too low even at thicknesses of 3 ft. to permit satisfactory vision so that such glass cannot be used to replace a glass cell. It has now been discovered that if the glass contains at least 17% K_2O, and if the total alkali metal oxide content does not exceed 25%, it can be employed as a window in "heavy" concrete. The specification gives a number of possible compositions showing sufficient gamma-ray absorption without too much loss of vision.

B.P. 764,886. Electromagnetic ion separator sources. To: U.S. Atomic Energy Authority (U.S.A.).

Electromagnetic ion separators ("calutrons") are employed in separating the isotopes of the elements. They are adaptable to the separation of macroscopic amounts of any mixture of isotopes which may be ionized. In general, an ion source of such separators projects ions of a polyisotopic material into a magnetic field. The ions travel in curved paths and the ions of greater mass describe flatter curves than the ions of lighter mass. The ions of the different paths are then collected at suitable points. The degree of separation depends largely on the stability of the forces producing these paths. The operations require an intense stable beam of positive ions projected from the ion generator, which means a high-density plasma surface which is extremely stable in shape, position, and ion density. These conditions are fulfilled by an ion generator with an ionization chamber, an arc cathode for supplying a stream of electrons to bombard the arc cathode for raising it to a thermionically emissive temperature, and a conductor carrying the arc current. Means responsive to variations in the length of the conductor maintain the stability of the arc current.

B.P. 765,100. Neutron logging apparatus. J. Tittman. To: Schlumberger Well Surveying Corporation.

In order to reduce the masking effect of drilling mud in borehole logging, a pad of material is provided for displacing the mud in the space where the neutrons migrate across the wall of the borehole. This pad is made of a material transparent to neutrons, e.g., solid aluminium. The neutron source may be a radium-beryllium pellet, the shield material cadmium or boron-carbide.